5-1999

Land-use and other Factors Affecting the Distribution of Aquatic Macroinvertebrates in the Richland Creek watershed on Walden Ridge in Tennessee

Jack Thomas Pickett
University of Tennessee - Knoxville

To the Graduate Council:

I am submitting herewith a thesis written by Jack Thomas Pickett entitled "Land-use and other Factors Affecting the Distribution of Aquatic Macroinvertebrates in the Richland Creek watershed on Walden Ridge in Tennessee." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Ecology and Evolutionary Biology.

James Drake, Major Professor

We have read this thesis and recommend its acceptance:

David A. Etnier, Dewey Bunting

Accepted for the Council:
Dixie L. Thompson

Vice Provost and Dean of the Graduate School

(Original signatures are on file with official student records.)

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LAND-USE AND OTHER FACTORS AFFECTING THE DISTRIBUTION OF AQUATIC MACROINVERTEBRATES IN THE RICHLAND CREEK WATERSHED ON WALDEN RIDGE IN TENNESSEE

A Thesis
Presented for the
Master of Science
Degree
The University of Tennessee, Knoxville

Jack Thomas Pickett
May 1999

DEDICATION

This thesis is dedicated to my daughter

Winter Faith Pickett

who provided invaluable motivation towards its completion.

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There are many people to whom I am grateful for making my time at the University of Tennessee so rewarding. I thank Dr. James Drake for his tolerant attitude toward a haphazard and somewhat occasional Graduate Student. I thank Dr. David Etnier both for being on my committee, and for teaching such interesting and useful lab courses. I thank Dr. Dewey Bunting for being on my committee, and for still teaching a pencil and paper version of biometry. I also am grateful to Dr. Sandy Echternacht for altering my view of reality through his course in zoogeography.

The greatest debt is owed to my wife, Ellie, who continually prodded me along when my academic progress started to drag, and who let me know when the critical moment arrived when sufficient data had been collected and it was time to go ahead and write the thesis.

ABSTRACT

In this study aquatic invertebrates were sampled in riffle habitats of the 4 branches of Richland Creek on Walden Ridge, Tennessee (1800 feet elevation). The 4 branches have low-gradient upper portions on the ridge top and high-gradient lower portions in the canyons that descend the ridge. Pine plantations (*Pinus taeda*) cover about 33% of the watershed, with the coverage of the 4 branch creeks varying from 6% to 90%. The pH and total alkalinity of the 4 branch creeks were found to be inversely correlated with the amount of pine plantation coverage of the watersheds of the creeks, with an average pH of 7.2 with 6% coverage and average pH of 6.0 for 90% coverage measured at the mouths of the creeks. In a comparison of 7 stream sites in pine plantations on the ridge with 7 nearby stream sites outside pine plantations, average pH was 6.8 outside pine plantations, and 5.6 inside pine plantations. The differences in water chemistry resulted in significantly lower species richness of all insect orders in the pine plantations except for Diptera. EPT species richness was also significantly lower. Diptera abundance was significantly higher in the pine plantation community. The Shannon community diversity index was significantly lower for the pine plantation community than the non-pine plantation community (2.29 versus 2.69). Community differences downstream from the pine plantations were not as pronounced. Three species of mayflies (*Drunella cornuta*, *Epeorus dispar*, and *Heptagenia* sp.) were excluded from the lower portion of the stream with 90% pine coverage due to their sensitivity to acidic conditions. Species richness, EPT richness, and the Shannon index were not significantly different in the 4 lower creeks. By the Jaccard coefficient of community similarity, the creek with 90% pine coverage was less similar to the other 3 creeks than they

were similar to each other. Seasonal species of mayflies and stoneflies resulted in the invertebrate abundance of the lower portion of the 4 creeks being dominated by stoneflies in the winter sampling period (12/97 to 1/98), and being dominated by mayflies in the spring sampling period (4/98 to 5/98). Stoneflies of the family Perlidae (*Acroneuria spp.*) were restricted to the lower portions of the 4 creeks, and stoneflies of the family Perlodidae were restricted to the upper portion of the creek, except for *Isoperla holochlora.* The restriction of species of *Acroneuria* to the lower portion of the creeks was thought to be the result of the unusual situation where the lowest gradient portion of the creeks occurred in the lower-order branches on the top of Walden Ridge.

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1. INTRODUCTION

The Study Purpose

It is the purpose of this thesis to survey the distributions of aquatic insects and crustaceans of the Richland Creek watershed located on Walden Ridge in Tennessee. The combination of relative ease of access to the 4 branches of Richland Creek combined with the large differences in the coverage of the drainages of these creeks by pine plantations make this an ideal system to evaluate in terms of the effects of land-use, stream gradient, and water chemistry on the distributions of aquatic invertebrates.

Walden Ridge is a peninsular-like appendage of the Cumberland Plateau, running in a general northeast-southwest direction (Figure 1). It is joined to the main plateau at the north end in the area of Crossville, Tennessee. On the western side, the ridge runs parallel to the main body of the Cumberland Plateau, with the long (about 60 miles) but narrow (3 to 4 miles) Sequatchie River Valley separating the two. To the eastern side, Walden Ridge overlooks the Valley and Ridge formations of the Great Valley of east Tennessee. For the purposes of this report, the southern end of Walden Ridge is considered to be where the ridge is traversed by the Tennessee River (Walden Gorge) near Chattanooga, Tennessee.

The surface of Walden Ridge slopes away from the Sequatchie Valley, so that almost the entire ridge drains southeastward to the Tennessee River. The Richland Creek system (the site of this study) is located in the northern half of Walden Ridge, and drains the area of the ridge above the city of Dayton, Tennessee.

The land use pattern of this 52.3 sq. mile watershed is complex. The 4 branches of Richland Creek vary in their coverage by pine plantations (*Pinus taeda*)

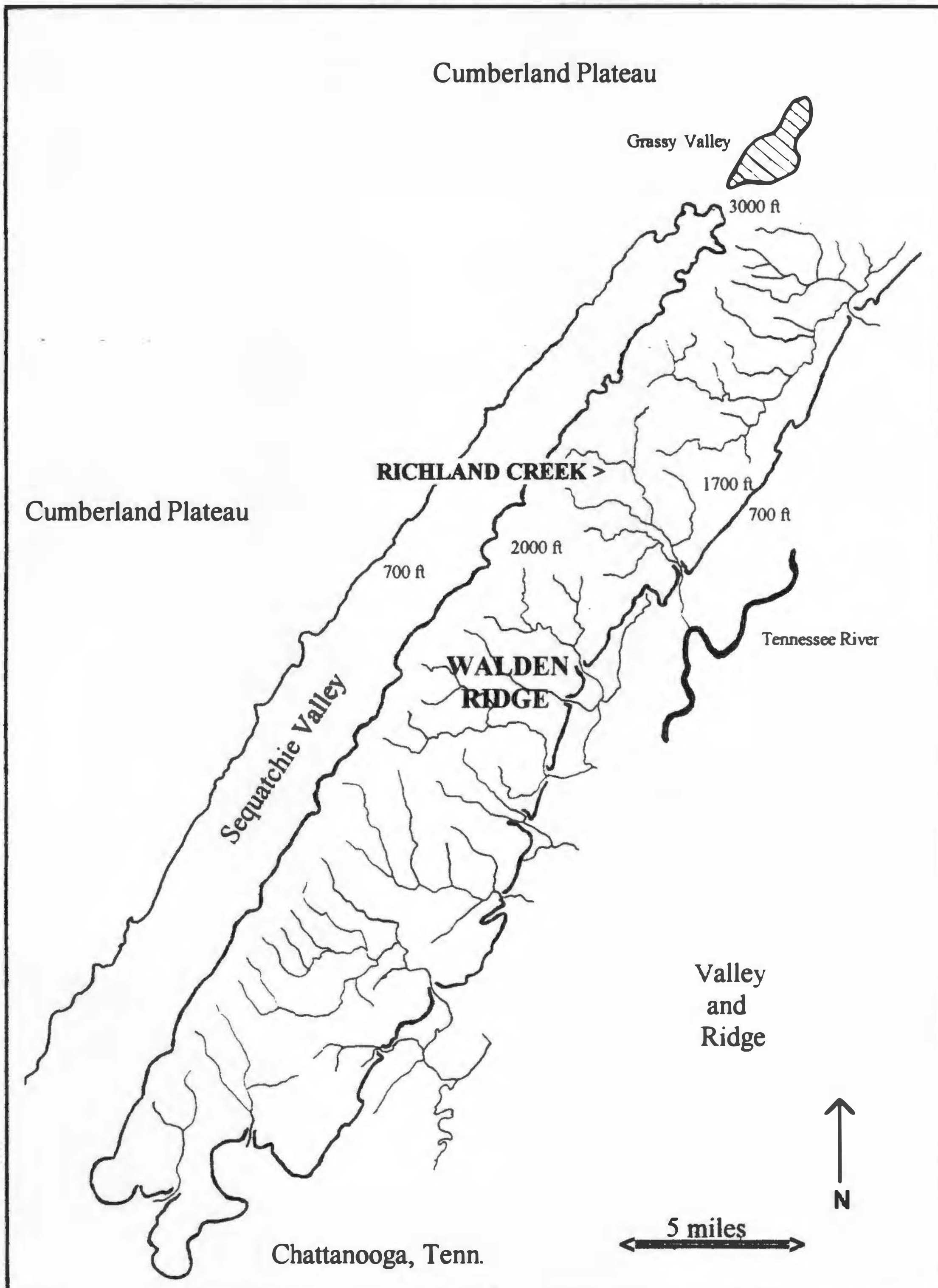

FIGURE 1. Walden Ridge and the Richland Creek study site.

from 6% for Morgan Creek to 90% for Laurel Creek (Figure 2). A focus of this thesis is the effect of the pine plantation coverage on stream chemistry and aquatic invertebrate distributions. The consideration of just the one land-use category of pine plantations may seem arbitrary, but this division is supported by high altitude aerial photographs, where the pine plantations stand out in sharp contrast as solid units compared to the mosaic of pasture, crop fields, residential, and deciduous forests (Figure 3).

Besides land-use patterns, these is also a clear division of the 4 creeks of the study area into the low-gradient upper portions on top of Walden Ridge and the high-gradient lower portions on the Cumberland Escarpment where the creeks descend the ridge.

A benefit of the coverage by tree farms is that a major portion of the steep canyons that descend the Cumberland Escarpment are contained within a "Pocket Wilderness" maintained by the Bowater paper company. Thus public access to the creeks in these canyons is relatively unrestricted, and most areas can be approached either by walking trails within the canyons, or by logging roads on the surface of the ridge.

Predictions

Because pine plantations modify the water chemistry of the streams that drain them, it is possible to make several predictions about the relationships between the amount of pine plantation coverage, water chemistry, and aquatic invertebrate distributions.

The first 2 predictions are concerned with water chemistry. There is a decline in soil pH after conversion of land to pine plantations. Once conversion has

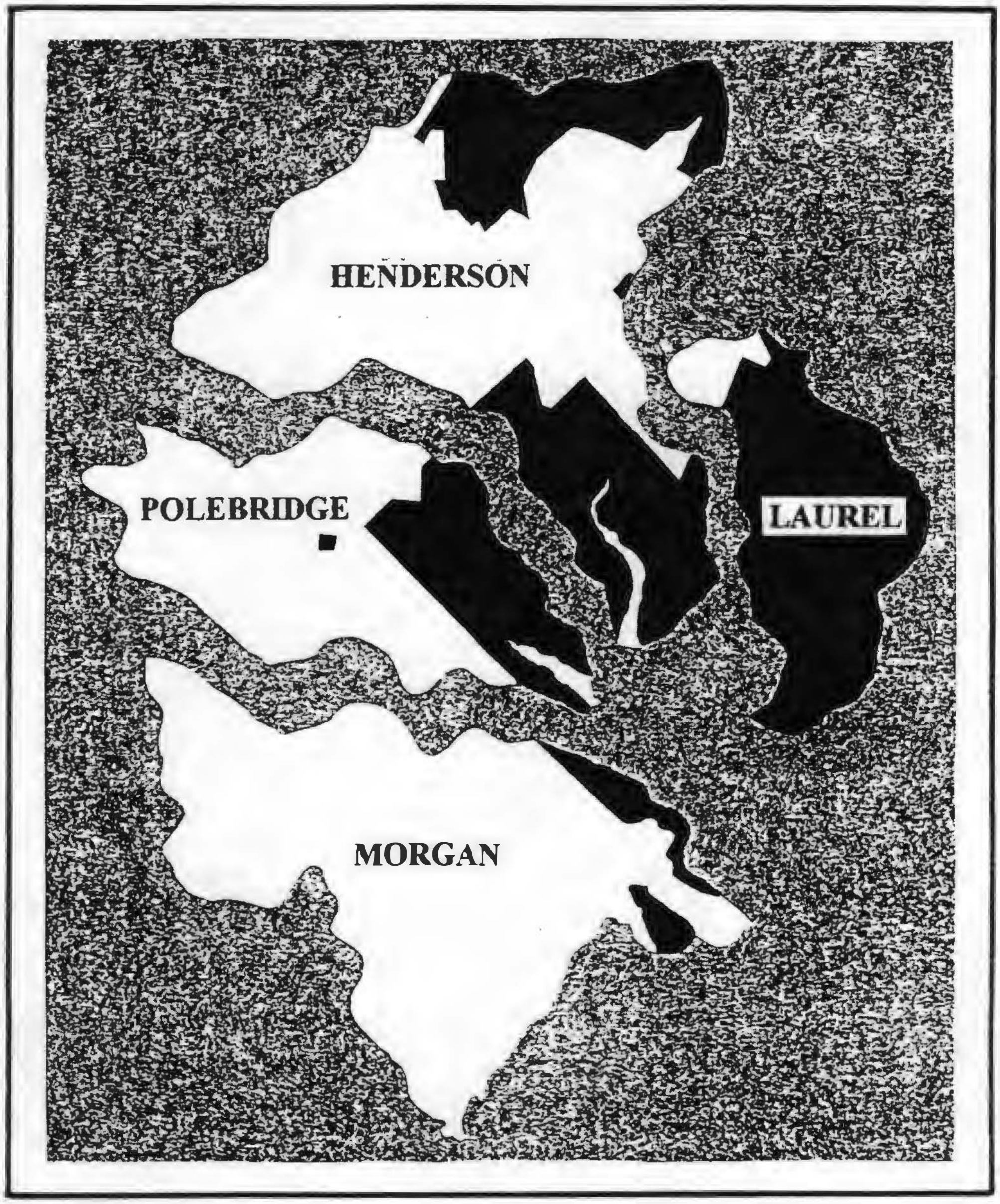

FIGURE 2. Map of the coverage by pine plantations of the four branches of Richland Creek. Black areas represent pine coverage. White areas represent all other types of land-use (native forests, agricultural land, and residential).

FIGURE 3. Aerial photograph demonstrating the two land-use categories used in this study (3/16/97). The dark area to the right is a portion of a pine plantation. The area in the photograph is a portion of the watersheds of Polebridge and Henderson Creeks on Walden Ridge.

occurred, soil pH varies between 4.2 to 5.2 range over the life of the trees (Rao, Sharma, and Shukla, 1997). The pine plantations in this study have been in existence since the late 1950s. There have not been many studies of the results of this lowering of pine plantation soil pH on stream chemistry or aquatic invertebrates, but there have been many studies concerned with the results of acidic deposition on stream chemistry and communities (Hyer, Webb, and Eshleman, 1995). In addition, there have been several experimental manipulations such as the study by Hall, Likens, Fiance, and Hendrey (1980) in which one of the streams in the Hubbard Brook National Experimental Forest was experimentally acidified to pH 4.0.

Concerning water chemistry, these studies show that with increased acidity the stream concentrations of Al, Ca, Mg, K, Mn, Fe, and Cd are elevated. Alkalinity decreases as a function of decreasing pH. Alkalinity represents the buffering capacity of the aquatic system (usually expressed in terms of equivalents of carbonate). As acid is added to the system, alkalinity drops because carbonate is converted to carbonic acid. This process has the effect of raising the free carbon dioxide of the system, so that as alkalinity and pH go down, free carbon dioxide rises. These basic chemical relationships suggest the following predictions.

PREDICTION 1. The pH at the mouths of the 4 streams should vary with the percentage of coverage by pine plantations, so that Laurel Creek with 90% coverage should have the lowest pH, and Morgan Creek with 6% coverage should have the highest pH. Sites on streams in the pine plantations on Walden Ridge should have lower pH values than sites not in pine plantations.

PREDICTION 2. Alkalinity of the four branches of Richland Creek should vary with the percentage of coverage by pine plantations in the same manner as pH. Free carbon dioxide should show an inverse relationship to pH and alkalinity.

Predictions 3 and 4 are concerned with changes in community composition of aquatic invertebrates that could result from the changes in water chemistry due to the coverage of parts of the watershed by pine plantations. Studies comparing terrestrial sites within and without pine plantations have shown lower species richness within the pine plantations. Although these studies have primarily focused on birds (Parker et al., 1994) (Repenning and Labisky, 1985), there are also studies that show lower diversity of small mammals (Langley and Shure, 1980), amphibians (Mitchell et al., 1997), and ground beetles (Niemela et al., 1993).

While little research exists on aquatic invertebrates communities in the streams of pine plantations, there is a large body of research concerning the effects of changes in water chemistry (mainly pH changes) on aquatic invertebrates. Many studies have examined the effects of acid rain on lentic and lotic habitats. There have also been several studies where the pH of streams was artificially lowered (Hall et al., 1980) (Hall, Driscoll, and Likens, 1987) (Kratz, Cooper, and Melack, 1994), as well as comparative studies of streams naturally differing in pH (Peterson, 1989).

If the aquatic community within the pine plantations follows the pattern of other animal studies, the stream sites within the pine plantations will have lower species richness and lower total abundance than stream sites not in pine plantations (Lehmann and Perevolotsky, 1992). Stream sites on the lower portions of the 4 creeks can be expected to have altered community composition with increasing coverage of the streams by pine plantations. The most acid-sensitivity species (mayflies) should decline (Peterson and VanEeckhaute, 1992), and less acid-sensitive species (stoneflies) should increase with decreasing pH (Griffith, Perry, and Perry, 1994). However, total richness and abundance should not differ greatly between high pH and low pH streams until the stream pH drops below 5.5 (Hall, Driscoll, and Likens, 1987). The relationships described in the above studies suggest the following 3 predictions.

PREDICTION 3. There should be some distribution patterns of aquatic invertebrates that correlate with the amount of coverage of the different creeks by pine plantations.

PREDICTION 4. The sites within the pine plantations on top of Walden Ridge should have lower species richness than the sites on Walden Ridge not in pine plantations. The species richness on the portion of Laurel Creek (90% coverage of the upstream watershed by pine plantations) that descends the escarpment should be lower than the species richness of the portion of Morgan Creek that descends the escarpment (6% coverage of the upstream watershed by pine plantations).

PREDICTION 5. In addition to species richness, there should be other differences in community composition and diversity related to the amount of pine coverage of the four streams.

The meaningful analysis of the results of this thesis as concerns predictions 3 to 5 is complicated by the physical differences among the 4 creeks. The most important of these differences is stream gradient, although differences in the size of the stream drainages is also a complicating factor. In regard to the gradient, it is fortunate that the 2 streams with the highest (90%) and lowest (6%) coverage by pine plantations have the 2 highest gradients of the four streams. The stream locations on the top of Walden Ridge selected for a comparison of sites within and without pine plantations are all of low gradient, and are all on primary or small secondary streams. Therefore, in the case of these sites, factors other than differences in pine coverage have been minimized. The last 2 predictions are concerned with spatial and temporal patterns of distribution of aquatic invertebrates that are unrelated to the presence of pine plantations.

PREDICTION 6. There should be some species restricted either to the high-energy and higher-order canyons of the escarpment, or to the less energetic and lower-order tributaries of the 4 branches on the top of Walden Ridge.

PREDICTION 7. Some species should exhibit seasonal patterns of abundance in the sites on the escarpment that were sampled both in the winter (12/97 to 1/98) and the spring (4/98 to 5/98).

2. THE STUDY SITE

Geological History of Walden Ridge

While the upper geological layers of Walden Ridge are those of the Cumberland Plateau to the west, the underlying structure is that of the Valley and Ridge zone to the east. In theory (Wilson, 1983), the western most of the series of folding and thrust-faulting that formed the Valley and Ridge system resulted in a range of low mountains above what is now the Sequatchie Valley. This is thought to have occurred in the Allegheny Orogeny (which began 225 million years ago). The ancestral Sequatchie River began headward erosion on the crest at the southern end of this range in the Mesozoic era. By the late Mesozoic (150 million years ago) the overlying resistant sandstone layers had been removed in the lower valley. This exposed the underlying limestone layers, resulting in accelerated erosion in the lower valley at the same time that sinkholes were forming above the upper valley. The result was a valley growing steadily to the north as the limestone dissolved and the upper sandstone layers collapsed. This process is still in progress today, with sinkholes enlarging in Grassy, Little, and Crab Orchard Coves, and headwater erosion occurring in the area of the Head of the Sequatchie.

The processes that formed the Sequatchie Valley resulted in the formation of the long and narrow Walden Ridge (about 60 miles by 6 miles) detached from the Cumberland Plateau by some 3 to 4 miles, except for the northern end. At this northern junction, the remains of the mountain range that once covered the Sequatchie Valley still exist, forming a low barrier that probably slows migration into Walden Ridge for those aquatic invertebrates with low dispersal abilities. This barrier of a low range of mountains is enhanced by the isolated watersheds of the Grassy Cove and other sinkholes.

The surface layers of Walden Ridge are primarily Pennsylvanian sandstone. This sandstone layer is about 500 feet thick on the Sequatchie Valley side of Walden Ridge, and about 1000 feet thick on the Tennessee Valley side of the Ridge. This sandstone contains strata of shale and coal. Abandoned coal mines are common on the main channel of Richland Creek, but Morgan Creek is the only one of the 4 branches with abandoned mines in the canyon that the creek flows through. All mines on Morgan Creek were below 1200 feet, and obvious mine seepage was only observed at one site.

The surface of Walden Ridge slopes to the southeastward in the direction of the Tennessee River. In the area sampled in this present study (the Richland Creek system), the typical drop from the higher side overlooking the Sequatchie Valley to the lower side overlooking the Tennessee River Valley is 200 to 300 feet in elevation. This results in almost the entire surface of the ridge draining in the direction of the Tennessee River.

The Richland Creek Watershed

The drainage area of Richland Creek above the old USGS stream gage at stream mile 5.2 (at the bridge in Morgantown above Dayton) is 52.3 square miles (Miller, 1982). Of this area, 48.1 square miles are drained by the 4 tributaries of Richland Creek considered in this study (Morgan, Polebridge, Henderson, and Laurel creeks). Most of the remaining area is the drainage of Paine Creek. This creek flows diagonally along the escarpment of Walden Ridge, joining Richland Creek near the parking lot of Pocket Wilderness. Paine Creek was not included in this study because of its small size and because it has very little of its drainage on the top of the Ridge. It mainly drains the Cumberland Escarpment.

The flood stage of Richland Creek was considered to be about 6000 cubic feet per second (cfs) of water through the old stream gage. The highest flow measured at the gage in this century was 14,000 cfs (February 27, 1903). The 100-year flood discharge is considered to be 18,000 cfs (Miller, 1982).

In very general terms, Morgan Creek and Laurel Creek drain the eastern side of Walden Ridge, and Polebridge and Henderson drain the western side of the Ridge (Figure 4). All 4 creeks separate from the main branch of Richland Creek lower than 1300 feet of elevation, so that the 4 branches all form canyons that climb Walden Ridge. These canyons can be up to 800 feet deep. All four creeks differ from the textbook lotic system where the headwater portion would have the highest gradient. In this case the headwater tributaries on the top of Walden Ridge are of relative low gradient and the middle portion is of high gradient. The main portion of Richland Creek formed by convergence of the four branches is again of relative low gradient after entering the floodplain below the Pocket Wilderness at around 840 feet elevation.

Gradients on Walden Ridge of the 4 creeks are typically 46 feet per mile. The gradient of Richland Creek is about 20 feet per mile in the vicinity of Dayton (Miller, 1982). The gradients of the 4 creeks on the escarpment vary widely. Figure 5 shows the gradient of the four branches from the point where they join Richland Creek to the point where they attain the top of Walden Ridge. Henderson and Polebridge creeks are similar to each other with a gradient of 114 feet per mile for Henderson and 130 feet per mile for Polebridge. Morgan Creek has a gradient of 585 feet per mile. Laurel Creek has a gradient of 1340 feet per mile on the escarpment.

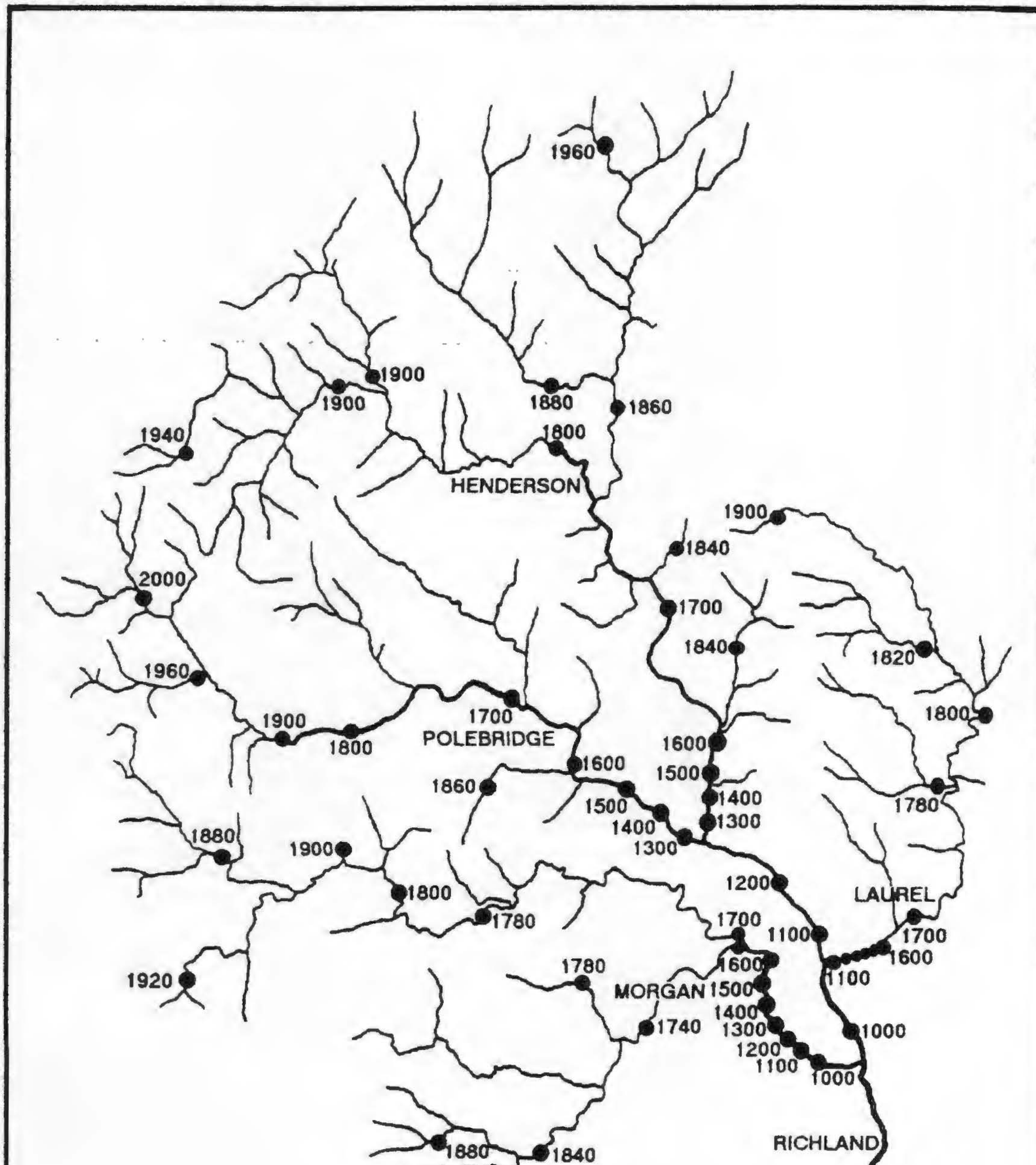

FIGURE 4. Map of the Richland Creek watershed and the sample sites.

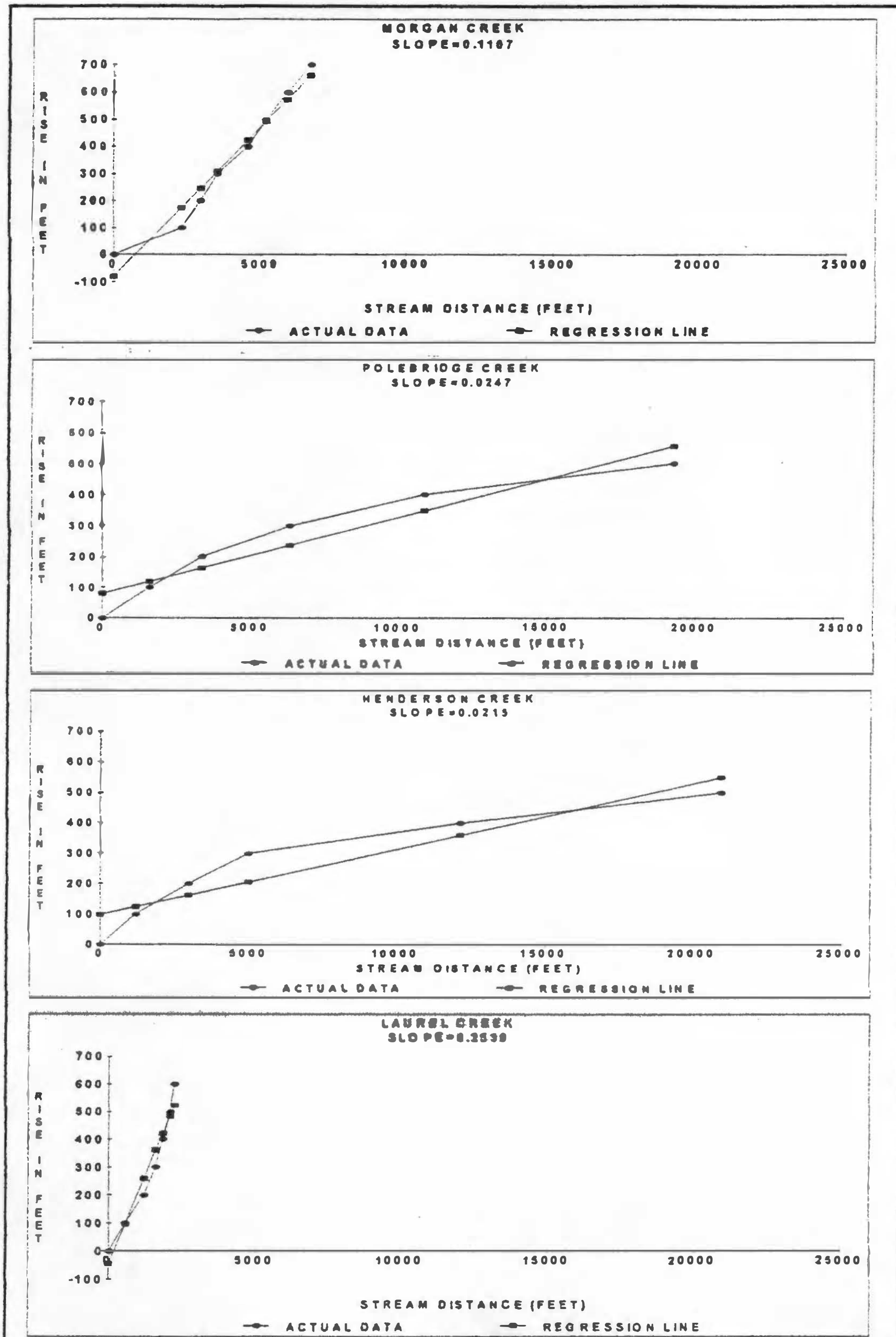

FIGURE 5. Gradients of the four branches of Richland Creek

The 4 creeks divide naturally into 2 pairs (Table 1). Morgan and Laurel both approach the edge of the ridge at a relatively low and constant gradient until they exit in a steep drop involving a waterfall. The waterfall on Morgan Creek is Snow falls, about 20 feet high. The waterfall at the point where Laurel Creek leaves the ridge is Laurel Falls. This waterfall is about 70 feet high.

Morgan Creek is the larger of this pair, draining about 14.9 sq. miles compared with 6.1 sq. miles for Laurel Creek.

The second pair of creeks consists of Polebridge and Henderson. Richland Creek splits into this pair at 1300 feet elevation. Although they differ in size, these 2 creeks have about the same average gradient between 1300 and 1700 feet. Unlike Morgan and Laurel creeks, Henderson and Polebridge do not have a clear point of exit from Walden Ridge. The canyon that contains Henderson Creek gradually disappears around the point where Summer City Road crosses the creek. Polebridge Creek undergoes major branching before reaching the top of Walden Ridge. The point where the main branch of Polebridge Creek emerges from the canyon is a clear drop-off at 1900 feet, but by the time the creek reaches that

TABLE 1. Drainage area and coverage by pine plantations of Richland Creek.

WATERSHED	AREA (square miles)	% PINE PLANTATION
MORGAN	14.9	6%
POLEBRIDGE	9.7	27%
HENDERSON	17.4	39%
LAUREL	6.1	90%
RICHLAND (above streams combined)	48.1	33%

altitude, it is much diminished in size because of the splitting off of Card and Corder creeks.

Polebridge and Henderson creeks also both have moderate amounts of coverage by pine plantations (27% for Polebridge, 39% for Henderson), at least when compared with the extreme values of the other two creeks (6% for Morgan, and 90% for Laurel).

While similar in coverage by pines and in gradient, these two creeks differ in drainage area. Polebridge drains an area of 9.7 sq. miles, while Henderson drains an area of 17.4 sq. miles.

The segments of 3 of the 4 creeks (Morgan, Polebridge, and Henderson) are similar as they climb the canyons of the Cumberland Escarpment. The water tumbles over boulders and small waterfalls, or makes fast runs over areas where the bottom is flat and clear of rocks. There are occasional riffle areas where the water flows over small rocks and boulders, with some gravel on the bottom, and usually some captured leaf litter and other organic debris. These riffle areas were the sites sampled in this study.

Laurel Creek differs from the other 3 creeks in that areas of flat bottom are rare. Most of Laurel Creek in this high gradient canyon consists of rapidly dropping water flowing around large boulders. Small waterfalls are common. Riffle areas suitable for sampling were infrequent, as smaller rocks are apparently swept out of this high gradient canyon in periods of high waterflow.

Once on Walden Ridge, the streams are typically low gradient. Flat sandstone bottoms are common on the higher-order sections of the creeks. Generally, as the source of a small branch is approached, the gradient becomes low, with the stream running through deciduous forests with loose sandy soil where the area is still wooded, or into a pasture where the land has been cleared. Where there is still forest, it is not unusual for the small branches to originate in a seasonal spring or spring seep. Where the land has been cleared, the small branches may originate in a wet meadow or grassy spring seep. It is becoming increasingly common for the small branches to begin in a series of impoundments. Pond building is an increasing activity on Walden Ridge.

In the areas that have been converted to pine plantations, almost all branches originate in wooded areas. While the flatter areas of the plantations are primarily a monoculture of pines, the steeper slopes and ravines around the streams tend to be dominated by a narrow strip of deciduous trees.

3. METHODS

The Sample Sites and Sampling Technique

The sites on Richland Creek sampled in this study were selected so that some spatial and temporal patterns might emerge from the collection data. The 4 creeks were sampled at every 100 foot rise in elevation as they climbed the escarpment of Walden Ridge. These 29 sites were sampled in both the winter (December 1997 to January 1998) and spring (April 1998 to May 1998).

The 31 sites on the top of Walden Ridge were selected in a more random manner, essentially based on ease of access for sampling. As a focus of this study was to compare streams on Walden Ridge in pine plantations with streams not in pine plantations, the sample sites on the Ridge tended to be concentrated either in the Morgan Creek watershed (very little pine coverage), or in the portion of the Laurel Creek and Henderson Creek watersheds covered by a single large pine plantation.

Seven sites in the Morgan Creek drainage were sampled for comparison with 7 sites in the pine plantation on Laurel and Henderson creeks (Figure 6). All 14 of these sites were sampled in a 4-day period of January, 1998.

An attempt was made to standardize the type of site sampled at all locations on the 4 branches of Richland Creek. The sites selected were riffle habitats where there was an undulating or broken flow of water over small to medium sized rocks. These riffle areas usually extended across the creek, or across a portion of the creek where the flow was split into sections. If the surface of the rocks was covered with sediments, so that when disturbed, a dirty plume was released into the water, the site

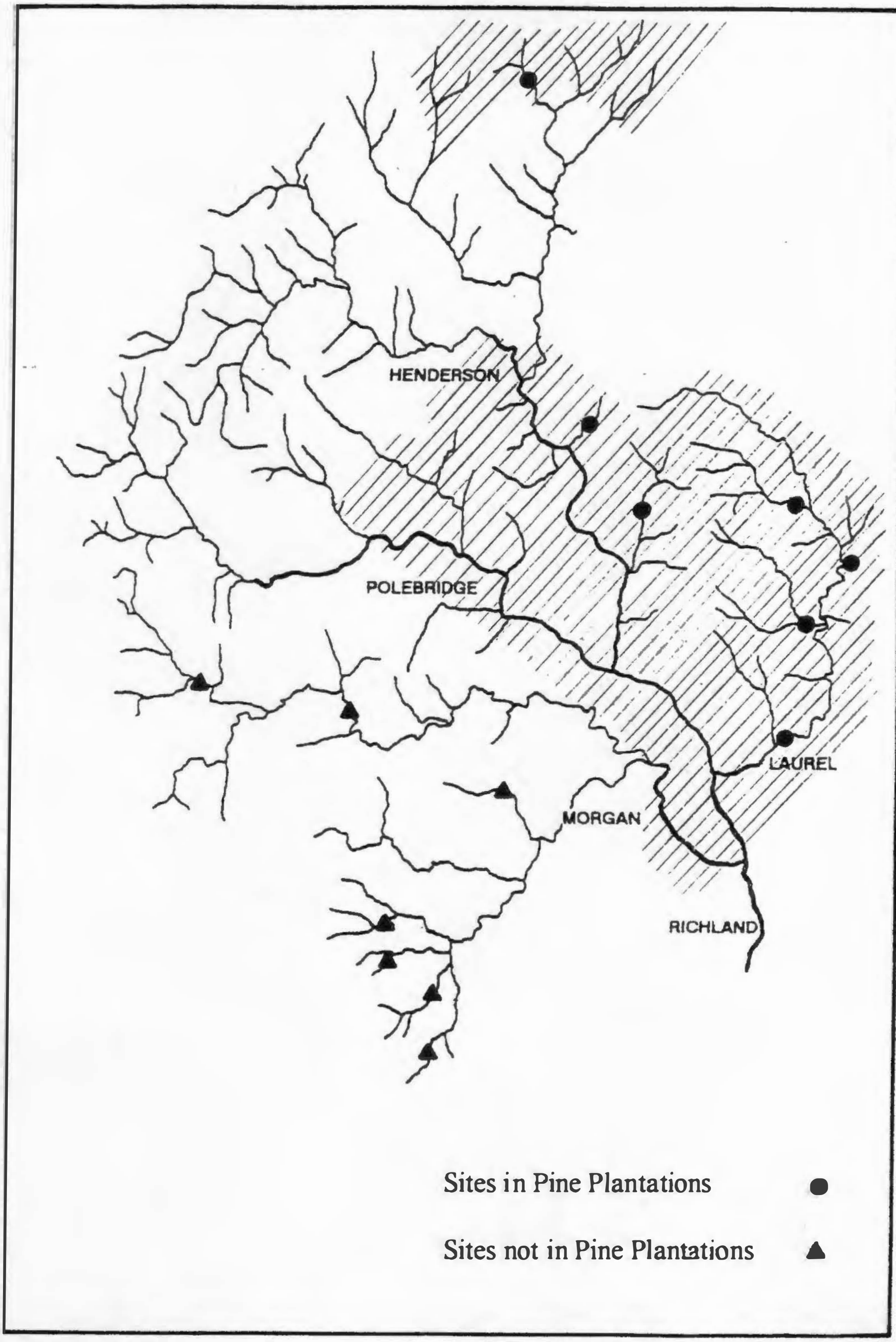

FIGURE 6. Sites sampled for a comparison of aquatic invertebrate communities in pine plantations with communities not in pine plantations.

was not considered to be energetic enough for sampling. If, on the other hand, the flow of water was over large boulders and of such depth and energy that sampling was difficult, the area was considered to be too energetic. This system worked well for standardizing the sites on the escarpment. However, it tended to fall apart as sampling moved into the smaller-order branches on the top of Walden Ridge. On the smallest branches it was often necessary to look for areas that were small waterfalls. Near the origins of most branches there were few rocks, with the creeks flowing through low gradient wooded areas and tending to have sandy bottoms and much organic material. Only a few of these sandy areas were sampled, usually in association with the study of intermittent springs and spring seeps.

Once a suitable site had been located, collections were made by disturbing the smaller rocks and sediments and collecting the invertebrates downstream with a hand-held wire screen. Some rocks were lifted at all sites and examined for flattened insects with strong clinging power, or attached caddisfly cases. At most sites there would be a few rocks with an algal mat which would be rubbed by hand to release the insects into the water.

It was not feasible to conduct the searches over a constant area. It was decided therefore, to maintain a constant effort for comparison purposes. Therefore each site was examined for approximately 1/2 hour.

The sites on the escarpment were selected at every 100-foot rise in elevation. The elevation was determined by identification of landmarks from contour maps and location by curves in the trails (where trails existed) and by the distance from small branch creeks.

While the 100-foot rise in elevation sites were systematically sampled in the winter and spring period of 1998, random sampling of sites in the Richland Creek system occurred from January, 1996 to November, 1998.

Identification of aquatic insects was made with the use of keys produced by Brigham, Brigham, and Gnilka (1982), and with additions to these keys produced by Etnier (1997). Identification of aquatic crustaceans was made with use of keys produced by Pennak (1989).

It was the original intention of this thesis to collect data from the 100-foot elevation sites on the lower portions of the 4 creeks for periods in the winter, spring, and late summer. Unfortunately, a prolonged drought starting in June, 1998 made sampling of the sites in the summer impossible (and in the fall as well). By late July, the flow of water was so low that riffle conditions no longer existed. This drought continued until early December, 1998, resulting in the lowest stream flows of at least the last 50 years.

Water chemistry analysis was performed by use of a LaMotte Limnology Test Kit (Model AM-02). The 4 streams were tested for pH, alkalinity, dissolved carbon dioxide, and dissolved oxygen. All tests were performed in the field at the site being tested. In general, all 4 branches of Richland Creek would be tested on the same day to standardize testing conditions.

Mapping of Land-Use Categories

The areas covered by pine plantations were mapped primarily by transferring points to maps from 2 high-altitude Tennessee Valley Authority (TVA) aerial photographs (NAPP numbers 9746-240 and 9746-242). These photographs were taken on March 16, 1997. Supplemental aerial photographs were taken from 3000 feet altitude on February 7, 1998. In a few areas not covered by the maps, or where it was not clear if the ground cover was pine plantations or deciduous forests, ground checks were made to determine forest type.

Most of the Richland Creek watershed is contained on the Tennessee Valley Authority map titled "7.5 Minute Series (Topographic) 110-SE: Morgan Springs Quadrangle". The remainder of the watershed is contained in the TVA map titled "7.5 Minute Series (Topographic) 110-NE: Melvine Quadrangle".

The calculation of coverage by pine plantation was made after the pine plantations were transferred to the TVA maps. Calculation of the values of pine coverage for the watersheds of Polebridge and Henderson creeks was complicated by the large width of the canyons that these two creeks flow through. These canyons do not have consistent pine coverage. The estimates of pine coverage for these 2 creeks is therefore not as accurate as for Morgan and Laurel creeks, where the escarpment canyons are narrow, and do not cut through the pine plantations.

Statistical Methods

All analysis of variance (Anova) in this study is based on procedures described in Sokal and Rohlf (1981). In most cases one-way analysis of variance involved columns of the 4 different creeks, with the data in the columns consisting of the abundances of sample sites on the creeks, or of repeated measurements of chemical parameters of the streams such as pH.

One-way Anova was also used to test the significance of differences between the two land-use categories (in pine plantations or not in pine plantations). In this case, the columns were the land-use categories, with the data being either the abundance of an insect order at the different sites in the land-use categories, or pH values of the different sites.

There are comparisons of species richness in this study. The richness of a land-use category, or of a creek is a cumulative measure where each individual site may or may not add new species to the overall richness of the land-use category or creek. Therefore, where the richness of the land-use categories or creeks was compared, a two-way Anova without replication was used, with the columns consisting of different orders of insects, and the rows consisting of the land-use categories or of the different creeks. The data in the cells would consist of a single value of the richness (number of species) of the insect order in the land-use type or creek.

Where EPT richness (Ephemeroptera, Plecoptera, Trichoptera) was measured, the same two-way Anova without replication was used, with the columns being the three orders (E, P, T) and the rows being the land-use categories, or different creeks.

The Shannon Diversity Indices of the 2 land-use categories and of 2 of the creeks (Morgan and Laurel) were compared for significance by use of the Student's *t*-test by a method developed by Hutcheson (1970).

The Shannon Index is calculated as:

$$\text{Shannon Diversity Index} = -\Sigma\pi_i \log p_i \qquad \text{with } p_i = n_i / \text{N}.$$

Therefore *pi* is the proportion of the total number of individuals occurring in species *i*, and **N** is the total number of individuals in all species.

For the t-test comparisons, the variance of each creek or land-use site is calculated as:

$$s^2 = \frac{(\Sigma \pi i \log^2 pi) - (\Sigma \pi i \log pi)^2 / n}{n}$$

where n is the number of species in the data set.

The value of t is calculated as :

$$t = \frac{\text{(Shannon Index for data set 1)-(Shannon Index for data set 2)}}{\text{square root of } (s_1^2 + s_2^2)}$$

The degrees of freedom for the t-test are calculated as:

$$DF = (s_1^2 + s_2^2) / [\ (s_1^2)^2/n_1 \ + \ (s_2^2)^2/n_2]$$

The Jaccard Coefficient of community similarity (CC_j) is calculated as:

$$CC_j = c\ /\ (s_1 + s_2 - c),$$

where s_1 and s_2 are the number of species in communities 1 and 2, and c is the number of species common to both communities.

An Fs value for an Anova was considered significant if it was greater than the table F value at the 5% level of significance ($\alpha = 0.05$).

4. RESULTS

Water Chemistry

Repeated measurements of the pH and total alkalinity of the 4 branches of Riceland Creek showed a consistent pattern (Table 2). When measurements were made at the mouths of the 4 creeks on the same day, Laurel Creek always had the lowest measurements for pH and total alkalinity, and Morgan Creek usually had the highest measurements for pH and total alkalinity. Polebridge and Henderson creeks were either at the same ph level as Morgan Creek, or slightly more acidic than Morgan, but never as acidic as Laurel. Polebridge and Henderson tended to be roughly equal to each other in pH and alkalinity when measurements were made on the same day.

TABLE 2. Water Chemistry Data for one of four dates sampled.

	Morgan	Polebridge	Henderson	Laurel
% Pine	6%	27%	39%	90%
		LOWER CREEK		
pH	7.2	6.8	6.8	5.5
Alkalinity	65	30	25	10
Carbon Dioxide	12	20.5	22.5	50
Dissolved Oxygen	6.0	5.5	5.5	5.5
		UPPER CREEK		
pH	6.8	6.8	6.5	6.0
Alkalinity	40	25	25	20
Dissolved Oxygen	4.5	3.5	3.5	4.5

The pH of Morgan Creek measured at the mouth was 7.2 on all 4 dates that it was sampled. The pH of Polebridge and Henderson creeks ranged from 6.8 to 7.2 on the 4 dates measured. The pH of Laurel Creek varied more than the other 3 creeks, from a low of 5.5 to a high of 6.3.

The alkalinity at the mouth of Morgan Creek was always higher than the other 3 creeks for any given date, with the 4 measurements being 20, 30, 35, and 65 ppm carbonate. The alkalinity of Polebridge and Henderson was always lower than that of Morgan when measured on the same day. Polebridge and Henderson tended to have alkalinity measurements that were close to equal on any given day that they were sampled. Measurements for Polebridge were 10, 20, 20, and 30 ppm carbonate. The alkalinity of Laurel Creek was always the lowest of the 4 creeks on any given day that all 4 creeks were sampled. The 4 alkalinity measurements for Laurel Creek were 5, 5, 5, and 10 ppm carbonate.

The free carbon dioxide of the lower parts of the 4 creeks was only measured on one date (11/18/98). This was near the end of the drought, and water flow was low. The stream with the lowest pH and alkalinity measurements (Laurel) had the highest free CO_2 (50.0 ppm), and the stream with the highest pH and alkalinity (Morgan) had the lowest CO_2 measured (12.0 ppm). Values were 20.5 ppm for Polebridge and 22.5 ppm for Henderson.

Dissolved oxygen (DO) was measured on one date (11/18/98). Again, this was a date when water flow was low. Measurements on the lower creeks at the points where they joined Richland Creek were: Morgan = 6.0 ppm, Polebridge = 5.5 ppm, Henderson = 6.0 ppm, and Laurel = 5.5 ppm. Measurements on the same day on the upper creeks (on the top of the Ridge) were Morgan = 4.5 ppm, Polebridge = 3.5 ppm, Henderson = 3.5 ppm, and Laurel = 4.5 ppm. The average measurement of

DO for the lower creeks was 5.8 ppm, and the average DO on the Ridge for the 4 creeks was 4.0 ppm. Due to the extremely low flow of the creeks on the date sampled, it is likely that these readings of dissolved oxygen are lower than normal.

Alkalinity and pH were also recorded for the sites in pine plantations or not in pine plantations that were sampled the last week of January, 1998 (Table 3).

The sites in the pine plantations were in a pH range of 5.0 to 6.0. The sites not in the pine plantations were in a pH range of 6.5 to 7.2. Alkalinity was at 0 ppm at one site in the pine plantation, indicating a complete loss of buffering capacity.

Aquatic Invertebrates of Richland Creek

Table 4 shows the species-list for the Richland Creek survey. Distributional maps for each species are contained in the Appendix. The results of the distributions of the members of the different orders follows:

ORDER EPHEMEROPTERA

Fourteen species of mayflies were collected in the Richland Creek system, from a total of 6 families.

Family Baetidae. The only widespread member of the family Baetidae was *Acentrella* sp. This species was mainly confined to the higher order streams as they

TABLE 3. Average pH and Alkalinity for the sample sites.

	Morgan	Polebridge	Henderson	Laurel
Average pH	7.2	7.0	7.0	6.0
Average Alkalinity	38	20	19	6
	7 Sites in Pines		7 Sites Not in Pines	
Average pH	6.8		5.6	
Average Alkalinity	24		7	

TABLE 4. Species list for Richland Creek.

	Morgan	Polebridge	Henderson	Laurel
# / # = sites on upper creek / sites on lower creek				
ORDER: EPHEMEROPTERA				
FAMILY: BAETIDAE				
Acentrella sp.	1/7	0/2	0/3	0/3
Baetis pluto	0/2			
FAMILY: HEPTAGENIIDAE				
Epeorus dispar	0/1	0/3	0/5	
Cinygmula subaequalis		0/1		
Heptagenia sp.	2/6	0/3	0/1	
Stenacron pallidum	2/0		1/1	1/0
Stenonema sinclairi	0/1	0/1	0/2	0/6
FAMILY: ISONYCHIIDAE				
Isonychia sp.	0/1		0/1	
FAMILY: AMELETIDAE				
Ameletus lineatus	8/3	1/6	3/4	1/4
FAMILY: LEPTOPHLEBIIDAE				
Paraleptophlebia sp.	1/0	1/0		
FAMILY: EPHEMERELLIDAE				
Drunella cornuta	0/5	0/2	0/1	
Ephemerella dorothea	0/5	0/4	0/2	0/2
Eurylophella funeralis	2/1	1/6	0/2	2/3
ORDER: ODONATA				
FAMILY AESHNIDAE				
Boyeria grafiana	1/1		1/2	2/3
Boyeria vinosa	1/0			
FAMILY: GOMPHIDAE				
Stylogomphus albistylus	0/1			
ORDER: PLECOPTERA				
FAMILY: NEMOURIDAE				
Amphinemura nigritta/delosa	2/1	0/1	0/3	0/1
FAMILY: TAENIOPTERYGIDAE				
Oemopteryx contorta	4/2	1/5	2/2	4/0
Taeniopteryx sp.	5/7	1/7	3/6	3/2
FAMILY: CAPNIIDAE				
Allocapnia sp.	1/0		1/0	1/0
FAMILY: LEUCTRIDAE				
Leuctra sp.	0/3	0/1	0/1	0/3
FAMILY: PELTOPERLIDAE	0/1			
FAMILY: PERLODIDAE				
Isoperla holochlora	0/6	0/3	0/2	0/2
Isoperla similis	2/0	2/3		
Cultus decisus	1/0		2/0	1/0
Clioperla clio	5/0			1/0
Diploperla duplicata	2/0			
FAMILY: PERLIDAE				
Acroneuria abnormis	0/5	0/1	0/3	1/5
Acroneuria carolinensis				1/0
Acroneuria lycorias				2/0
Eccoptura xanthenes	1/0			

TABLE 4 (continued)

ORDER: MEGALOPTERA	MORGAN	POLEBRI.	HENDER.	LAUREL
FAMILY: CORYDALIDAE				
Nigronia fasciatus	1/0			
Nigronia serricornis	3/2	1/1	3/3	3/0
FAMILY: SIALIDAE				
Sialis sp.	2/0			
ORDER: TRICHOPTERA				
FAMILY: HYDROPSYCHIDAE				
Diplectrona modesta	4/0	2/1	3/1	1/1
Cheumatopsyche sp.	3/0		1/1	1/0
Hydropsyche betteni	0/1		2/0	1/2
Ceratopsyche sparna	1/1		0/2	
FAMILY: PHILOPOTAMIDAE				
Dolophilodes distinctus	1/3		0/1	0/1
FAMILY: RHYACOPHILIDAE				
Rhyacophila glaberrima	2/1		0/1	1/2
Rhyacophila (invaria group)	1/0			
Rhyacophila torva				0/1
FAMILY: LEPIDOSTOMATIDAE				
Lepidostoma sp.	1/0	0/2	0/1	0/1
FAMILY: LIMNEPHILIDAE				
Ironoquai punctatissima	3/0			
Playtocentropus radiatus	1/0	1/0		1/0
Pycnopsyche sp.		1/0		
Pycnopsyche guttifer	3/2			2/0
FAMILY: UENOIDAE				
Neophylax aniqua				0/2
Neophylax wigginsi	3/2			
ORDER: COLEOPTERA				
FAMILY: PSEPHENIDAE				
Psephenus herricki	0/3	0/1		0/1
FAMILY: EUBRIIDAE				
Ectopria sp.	0/1			1/1
ORDER: DIPTERA				
FAMILY: TIPULIDAE				
Antocha sp.				0/1
Tipula sp.	4/1	1/3	3/0	1/3
FAMILY: TANYDERIDAE				
Protoplasa fitchi			1/0	
FAMILY: CHIRONOMIDAE				
SubFamily Orthocladinae			1/0	1/1
S. F. Chironominae/Chironomini	1/0			
FAMILY: SIMULIIDAE				
Prosimulium mixtum	3/1	1/3	2/1	3/1
ORDER: ISOPODA				
FAMILY: ASELLIDAE				
Asellus racovitzai	5/0	1/0		
Asellus forbesi	1/0		1/0	
ORDER: AMPHIPODA				
FAMILY: GAMMARIDAE				
Gammarus minus	5/3	1/1	2/0	
ORDER: DECAPODA				
FAMILY: CAMBARIDAE				
Cambarus bartoni	2/1		0/1	0/1

descended the escarpment. It was found at only one site on top of Walden Ridge, and that site was just above Snow Falls, which is the point where Morgan Creek exits the Ridge.

Baetis pluto was found at one site on Richland Creek and one site on lower Morgan Creek.

Family Heptageniidae. Five members of the family Heptageniidae were found in the Richland Creek system. Two species, *Stenonema sinclairi* and *Epeorus dispar* were confined to the lower higher-order streams, and were not present on top of Walden Ridge. *Epeorus dispar* was not present in Laurel Creek. *Heptagenia* sp. was present in Richland Creek, lower Polebridge Creek, one site in Henderson Creek, and in upper and lower Morgan Creek. This species was not present in Laurel Creek. *Heptagenia* sp. was strongly seasonal, with 15 spring sites and 0 winter sites. *Stenacron pallidum* was collected at 5 sites with no obvious distributional pattern. *Cinygmula subequalis* was collected at only one site in lower Henderson Creek.

Family Isonychiidae. One member of the family Isonychiidae was collected, *Isonychia* sp. This mayfly was present at 4 sites in Richland Creek, lower Morgan Creek, and lower Henderson Creek. *Isonychia* sp. was collected at no sites on the top of Walden Ridge.

Family Ameletidae. One member of the family Ameletidae was found in the Richland Creek system, *Ameletus lineatus*. This mayfly was widely distributed at 33 sites, from the main branch of Richland Creek to very small primary streams. There was no clear seasonal pattern.

Family Leptophlebiidae. One member of the family Leptophlebiidae, *Paraleptophlebia* sp., was collected at 2 sites. Both specimens collected had deteriorated by the time of identification, so I was not able to determine the species.

Family Ephemerellidae. Three members of the family Ephemerellidae were collected in the Richland Creek system. *Drunella cornuta* and *Ephemerella dorothea* were both confined to the higher-order streams on the escarpment and the main branch of Richland Creek. Both of these species were also only collected in the spring season.

Eurylophella funeralis was widespread at 18 sites located on top of Walden Ridge, on the lower branches of all 4 creeks, and in the main branch of Richland Creek.

ORDER ODONATA

Family Aeshnidae. There were 2 species of the family Aeshnidae present in the Richland Creek watershed. *Boyeria grafiana* was the only dragonfly that was widespread in the high-energy sites that were sampled in this study. The closely related *Boyeria vinosa* was collected at just one site in Morgan Creek (1780 foot site). On the 100-foot sites on the escarpment, *Boyeria grafiana* was present in low abundance. Typically only one specimen would be collected at a given site, but by late spring, the single dragonfly could easily out-weight the specimens of all other species collected at the site.

Family Gomphidae. *Stylogomphus albistylus* was collected at one site in lower Morgan Creek (1000 foot site). This dragonfly was collected on August 11, 1998, during the drought when the flow of water was very low. Thus *Stylogomphus albistylus* was not collected under the normal high-energy conditions that were part of the normal collection criteria.

ORDER PLECOPTERA

Family Nemouridae. The family Nemouridae was represented by only one species, *Amphinemura nigritta/delosa*. This stonefly was present on the lower branches of all 4 creeks, and at 2 sites on top of Walden Ridge on Morgan Creek. *Amphinemura nigritta/delosa* was strongly seasonal, with collections only being made in the spring.

Family Taeniopterygidae. This family was represented by 2 species, *Oemopteryx contorta* and *Taeniopteryx* sp. Both these species of stoneflies were widespread on both the top of the Ridge and in the lower branches of the creeks. Both species were also strongly seasonal, with all specimens being collected in the winter. It was not unusual for *Oemopteryx contorta* and *Taeniopteryx* sp. to both be collected from the same site. Usually *Taeniopteryx sp.* would be present in higher abundance than *Oemopteryx contorta* when the 2 occurred at the same site.

Family Capniidae. Specimens of *Allocapnia* stoneflies were collected at 3 sites in the Richland Creek watershed. Because identification can only be made from adult males, I was unable to identify to species.

One site where *Allocapnia* was collected was in a small intermittent spring-fed stream on upper Morgan Creek. The other sites where *Allocapnia* was collected were a small primary branch of Henderson Creek and a small branch of Laurel Creek. Both of these sites were in pine plantations.

Family Leuctridae. *Leuctra* sp. was the only species of the family Leuctridae collected in the Richland Creek watershed. This stonefly was restricted to the lower portions of the 4 creeks. It was collected at 7 sites in the spring, but only 2 in the winter.

Family Peltoperlidae. In the Richland Creek system, larvae of these roach-like stoneflies were found only in 2 small (but permanent) springs that emerge above the walking trail near the Pocket Wilderness parking lot. Identification of Peltoperlidae larvae beyond family was not attempted.

Family Perlodidae. Five species of the family Perlodidae were identified in the Richland Creek watershed. Three of these species were confined to the upper portion of the creeks on top of Walden Ridge. These were *Cultus decisus, Clioperla clio*, and *Diploperla duplicata.* In contrast to these 3 species, *Isoperla holochlora* was found only in the lower creeks as they descended the escarpment. *Isoperla similis* was found only in the 2 creeks with the lowest percent coverage by pine plantations (Morgan and Polebridge). *Isoperla similis* was also strongly seasonal, being found only in the winter sampling.

Family Perlidae. Four species of the family Perlidae were found in the Richland Creek watershed. *Acroneuria abnormis, Acroneuria carolinensis,* and *Acroneuria lycorias* were all present in the lower portions of the 4 streams, as well as in the main channel of Richland Creek. *Acroneuria abnormis* and *Acroneuria lycorias* were found at one site on top of Walden Ridge at 1700 feet altitude on Laurel Creek.

Eccoptura xanthenes was found only at the 1800 foot site on Morgan Creek.

ORDER MEGALOPTERA

Family Corydalidae. Both species of the genus *Nigronia* were collected in the Richland Creek system. *Nigronia serricornis* was a widespread species, likely to be encountered anywhere from the main channel of Richland creek to small primary streams on the top of Walden ridge. Generally *Nigronia serricornis* would be present in low abundance, typically with only one or 2 individuals being collected. However, by late spring a single individual could easily out-weigh all other specimens collected at the site combined. *Nigronia serricornis* was similar in distribution, abundance, and size to the dragonfly *Boyeria grafiana.*

Nigronia fasciatus was collected at only one site. This site was a small intermittent spring that flowed into Morgan Creek near the 1860 foot site.

Family Sialidae. *Sialis* sp. was collected at 2 sites in upper Morgan Creek (1860 and 1880 foot sites). This alderfly was present in low abundance with only one specimen being collected at each location.

ORDER TRICHOPTERA

Family Hydropsychidae. Four members of the family Hydropsychidae were found in the Richland Creek system. All 4 species tended to have distributions that covered most of the Richland Creek system. *Diplectrona modesta* had a widespread distribution, and was present on the upper and lower portions of all four creeks. *Cheumatopsyche* sp. was present at only 6 sites, but they were widespread. *Hydropsyche betteni* was also collected at 6 sites that were widespread. *Ceratopsyche sparna* was collected at 5 sites, 4 on the lower creeks, and one on top of Walden Ridge.

Family Philopotamidae. Only one member of the family Philopotamidae was found in the system, *Dolophilodes distinctus.* This caddisfly was found at 6 sites on the lower creeks, and at one site on top of Walden Ridge (1780 foot site on Morgan Creek).

Family Rhyacophilidae. Three species of the Family Rhyacophilidae were found in the Richland Creek watershed. Only *Rhyacophila glaberrima* was collected at more than one site. This caddisfly was collected from the lower portion of Morgan, Henderson, and Laurel creeks, and on top of the Ridge on Morgan and Laurel creeks.

A member of the invaria group of *Rhyacophila* was collected at Morgan Springs (1900 foot site of Morgan Creek). *Rhyacophila torva* was collected at the 1300 foot site in lower Laurel Creek.

Family Lepidostomatidae. *Lepidostoma* sp. was collected at 5 sites. Four were in the lower portions of Polebridge and Laurel creeks, and one was at a 1920 foot site in upper Morgan Creek.

Family Limnephilidae. Four members of the family Limephilidae were found in the Richland Creek watershed. Three of the 4 were collected only at isolated sites on top of Walden Ridge. *Ironoquia punctissima* was collected at 3 small streams in the Weller Branch of Morgan Creek (1880, 1860, and 1920 feet altitude). *Playtocenrtopus radiatus* was collected at 3 sites on top of Walden Ridge, one in Morgan Creek (1860 foot site), one in Polebridge Creek (1860 foot site), and one in Laurel Creek (1780 foot site). *Pycnopsyche* sp. was collected only at the 1860 foot site on Polebridge Creek. *Pycnopsyche guttifer* was collected at 3 sites in the lower portion of Morgan and Richland creeks, at 3 sites on top of the Ridge in Morgan Creek, and at 2 sites on the Ridge in Laurel Creek.

Family Uenoidae. Two members of the family Uenoidae were collected from the Richland Creek watershed. Both were restricted to a single creek. *Neophylax wigginsi* was found at 2 sites in lower Morgan creek (1200 and 1300 foot sites), and 3 sites on the top of the Ridge in Morgan Creek. Therefore this caddisfly was found only in the creek with the lowest percentage coverage by pine plantations.

Neophylax aniqua was found at only 2 sites, both in lower Laurel Creek (1300 and 1400 foot sites). Therefore this caddisfly was found only in the creek with the highest percentage coverage by pine plantations. Species of Neophylax were identified using keys provided by Etnier (1997).

ORDER COLEOPTERA

Family Psephenidae. The water penny, *Psephenus herricki*, was collected at 7 sites, all in the higher-order lower parts of the Richland Creek system.

Family Eubriidae. The false water penny, *Ectopria* sp. was found at only 3 sites, 2 in the lower parts of Morgan and Laurel creeks, and one site on top of the Ridge (the 1800 foot site in Laurel Creek).

ORDER DIPTERA

Family Tipulidae. Two members of the family Tipulidae were collected in the Richland Creek system. *Tipula* sp. was widespread throughout the upper and lower portions of the system. *Antocha* sp. was collected at only one location, the 1500 foot site in Laurel Creek.

Family Tanyderidae. A single specimen of *Protoplasa fitchi* was collected at the 1500 foot site on Laurel Creek.

Family Chironomidae. Two members of the family Chironomidae (the "non-biting midges") were collected in the Richland Creek system. Neither was widespread. The subfamily Orthocladinae was collected in upper and lower Laurel Creek , and in upper Henderson Creek. The subfamily Chironominae, tribe Chironomini, was collected at one site in upper Morgan Creek.

Family Simuliidae. One species of the family Simuliidae (the "black flies") was widespread throughout the Richland Creek system. *Prosimulium mixtum* was collected in the upper and lower portions of all 4 creeks. Generally only a few individuals would be collected, but occasionally this species would be present in extremely high abundance. The larvae would sometimes be present in colonies of hundreds of individuals on the underside of a rock. Both sites where *Prosimulium mixtum* was present in high abundance were in Laurel Creek, the drainage with 90% coverage by pine plantations.

ORDER ISOPODA

Family Asellidae. Two species of the family Asellidae were collected from the Richland Creek system. *Asellus (Caecidotea) racovitzai* was collected from several sites in the Morgan Creek branch, but all were sites in small primary branches associated with intermittent springs, spring seeps, or in one case, a wooded spring-fed pond. *Asellus racovitzai* was also collected at one site in Polebridge Creek associated with a large area of wetlands and small intermittent springs.

Asellus (Caecidotea) forbesi was collected from the same site in Polebridge Creek as *Asellus racovitzai*. *Asellus forbesi* was also collected from one site in upper Henderson Creek where a small primary stream emerged from a wooded wetland.

No isopods were collected in the high-energy riffle sites typically sampled in this study, either on the top of the Ridge, or on the escarpment.

Only isopods of the genus *Asellus* were found in the part of the Richland Creek system sampled for this study. Isopods were also collected from 3 sites on Walden Ridge in the watershed south of the Richland Creek watershed (Sale Creek). These sites contained *Asellus racovitzai*. They were similar to the sites containing isopods on Richland Creek in that they were associated with spring seeps or small spring-fed creeks.

In contrast to the sites on top of Walden Ridge were sites in the area around Dayton in the Tennessee River Valley. Most of the small streams and springs arising in this area contained isopods of the genus *Lirceus*. *Lirceus fontinalis* was found at three sites around Dayton, and *Lirceus brachyurus* was collected from a spring near Graysville in the Sale Creek watershed. Unlike the low-energy sites on Walden Ridge where isopods were collected, isopods were often found in riffle habitats in the Tennessee Valley.

The area at the junction of Walden Ridge and the Cumberland Plateau was also examined for isopods. Like the Richland Creek watershed, no isopods were collected from the normal energetic surface runoff streams on Walden Ridge above Spring city. However, a spring in Grassy Cove (the large sinkhole above the Sequatchie Valley) contained the isopod *Lirceus fontinalis*. *Lirceus alabamae* was collected from a site in the upper Sequatchie Valley on the Sequatchie River.

ORDER AMPHIPODA

Family Gammaridae. One member of the family Gammaridae was found in the Richland Creek system. This species, *Gammarus minus*, was widespread in the creeks on top of Walden Ridge (except for Laurel Creek), but in the higher-energy sites on the lower creeks, it was only found in Morgan and Polebridge creeks. In the lower portion of the creeks, the amphipod was typically present in low abundance, with never more than two specimens being taken from one site. At these high-energy riffle sites, the amphipods were always in leaf packs.

On the top of Walden Ridge, *Gammarus minus* was present in much higher abundance at the sites where it was collected. Anywhere that leaf packs were present, this amphipod was likely to be collected. This would typically be the small primary branches flowing through deciduous forests. If there was an intermittent spring feeding the creek, or a spring seep, amphipods were usually present.

Although no amphipods were collected from the creek with the highest percentage coverage by pine plantations (Laurel Creek), two sites in Henderson Creek that were in pine plantations contained *Gammarus minus*.

Gammarus minus was also collected from the upper Sequatchie Valley in the Sequatchie River.

ORDER DECAPODA

One member of the order Decapoda was collected from the Richland Creek system. In general, crayfish were not present in the high-energy riffle habitats sampled in this study. However, if a crayfish was spotted in one of the pools of the creeks, it was examined. If it was possible to identify sex in the field, only breeding adult males were retained.

Family Cambaridae. *Cambarus bartoni* was collected at 6 locations in the Richland Creek system, from the main channel of Richland Creek to a fairly small branch of Morgan Creek on top of Walden Ridge.

Springs on Walden Ridge in the Richland Creek Watershed

Permanent springs with a flow large enough to support the special aquatic vegetation associated with springs are virtually unknown on the portion of Walden Ridge surrounding the Richland Creek study area. There are 4 springs named on the

TVA Map titled "Morgan Springs Quadrangle". The species lists for these 4 springs appear in Table 5 to Table 8.

Morgan Springs is the name of an old community associated with a hotel/resort that once served as an escape from the heat of the summer in the Tennessee and Sequatchie valleys. There is a permanent spring here, but it is a small trickle of iron-laden mineral water that falls into a natural bowl shaped rock. This mineral water was one of the attractions of the hotel. There is also an intermittent spring that rises in a stone structure (now collapsed) which was originally constructed by the hotel as a mineral bath. This intermittent spring ran dry in the drought of 1998, although it generally flows through most summer seasons. There is also a runoff stream that feeds into the Morgan Springs site.

The species richness of Morgan Springs is high, due to the clean spring water, steep slope of the little canyon that the springs are in, and the gravelly nature of the stream bed.

Cumberland Springs, like Morgan Springs, is listed on maps in big print, not because of the size of the spring, but because it was once the center of another resort community where people came to improve their health by drinking the mineral water. The spring is small enough that its discharge is carried underneath a road through a 2-inch pipe. Iron deposits form around the outflow of this pipe. There was little to sample at the site of this mineral spring.

Frazier Spring has been impounded as part of a small lake, so collection from this spring was not possible. Impoundment has been the fate of many of the intermittent (and possibly of many permanent) springs on Walden Ridge. In the drought of 1998, it was easy to spot the ponds with spring sources. They were the ones that did not dry up.

TABLE 5. Species list for Morgan Spring.

ORDER	FAMILY	SPECIES
EPHEMEROPTERA	AMELETIDAE	*Ameletus lineatus*
PLECOPTERA	TAENIOPTERYGIDAE	*Oemopteryx contorta*
PLECOPTERA	TAENIOPTERYGIDAE	*Taeniopteryx* sp.
PLECOPTERA	PERLODIDAE	*Clioperla clio*
PLECOPTERA	PERLODIDAE	*Diploperla duplicata*
TRICHOPTERA	RHYACOPHILIDAE	*Rhyacophila glaberrima*
TRICHOPTERA	RHYACOPHILIDAE	*Rhyacophila (invaria group)*
TRICHOPTERA	LIMNEPHILIDAE	*Pycnopsyche guttifer*
TRICHOPTERA	LIMNEPHILIDAE	*Goera fusculata*
TRICHOPTERA	UENOIDAE	*Neophylax wigginsi*

TABLE 6. Species list for Rowe Spring.

ORDER	FAMILY	SPECIES
TRICHOPTERA	LEPTOCERIDAE	*Oecetis inconspicua*
COLEOPTERA	DYTISCIDAE	*Thermonectus basillaris*

TABLE 7. Species list for Spring on Rocky Creek.

ORDER	FAMILY	SPECIES
ODONATA	CORDULEGASTRIDAE	*Cordulegaster obliquua*
MEGALOPTERA	CORYDALIDAE	*Chauliodes pectinicornis*
COLEOPTERA	DYTISCIDAE	*Agabus gagates*
ISOPODA	ASELLIDAE	*Asellus racovitzai*
AMPHIPODA	GAMMARIDAE	*Gammarus minus*

TABLE 8. Species list for Periwinkle Spring in Grassy Cove.

ORDER	FAMILY	SPECIES
ODONATA	CORDULEGASTRIDAE	*Cordulegaster erronea*
PLECOPTERA	PELTOPERLIDAE	
TRICHOPTERA	HYDROPSYCHIDAE	*Diplectrona modesta*
TRICHOPTERA	SERICOSTOMATIDAE	*Fattigia pele*
ISOPODA	ASELLIDAE	*Lirceus brachyurus*

Paine Springs has been cartographically misplaced. It is not at either the location given on the TVA map of the Morgan Springs Quadrangle, or the location on the Tennessee Atlas and Gazetteer. This spring must exist somewhere near the main branch of Laurel Creek around 1800 feet elevation, but because the entire surrounding area has been converted to a pine plantation, there are no man-made landmarks to go by, or neighbors to ask for a location.

Rowe Spring in the watershed on Walden Ridge north of Richland Creek, was another spring in an area that has been converted to a pine plantation. A logging road runs adjacent to the spring. Whatever the past nature of this spring, it is now more of a permanent wetland than a spring. There is standing water, but in July, 1998, when I sampled it, the water temperature was tepid. There was no apparent outflow channel from this spring.

Intermittent springs and spring seeps are fairly common on Walden Ridge. The Weller Branch of Morgan Creek was surveyed more intensely than other areas in a search for these small springs. Near the Weller Branch there is also a fairly large intermittent spring that flows into Rocky Creek in the watershed to the south of Richland Creek on Walden Ridge.

In addition to intermittent springs and spring seeps, the Weller Branch contains a spring-fed wooded pond in a sinkhole in the woods of the Weller Branch. This pond dries up in dry summers, so it contains no fish.

The small wooded springs and spring seeps of the Weller Branch were unusual in that as a primary stream was followed to its source in one of these small intermittent springs, the richness and abundance of insects dropped off, and the stream became dominated by crustaceans. Typically the portion of these small spring-fed streams near the source were dominated by the Isopod *Asellus racovitzai*, and the Amphipod *Gammarus minus*.

Periwinkle Spring is not in the Richland Creek watershed, but in the Grassy Cove sinkhole above the northern end of the Sequatchie Valley. The spring is located below a sharp bend in Highway 68 as it enters Grassy Cove from the east. In the winter, the spring is visible from the highway. Unlike the springs on Walden Ridge, Periwinkle Spring is a permanent spring of a flow sufficient to support the specialized aquatic vegetation associated with springs.

5. DISCUSSION

Stream Gradients

A problem with analysis of data from the 100-foot elevation sites on the lower creeks is that it is difficult to separate out effects from the three habitat variables of stream size (watershed size), gradient, and differences in water chemistry due to the percentage coverage of the watershed by pine plantations. The 2 difficulties in this regard are that the pair of creeks with the highest pine coverage (90%) and lowest pine coverage (6%) have different stream gradients, and the pair of creeks with nearly identical gradients have similar amounts of pine coverage.

Table 9 shows an arrangement of the creeks from lowest gradient (0.022) to highest (0.254). The mean abundance of the sites on the four creeks do arrange in a manner so that sample abundance is inversely correlated with increasing stream gradient. The mean abundances of the 4 creeks did not arrange in a manner correlated with either watershed size or percent coverage by pines. The 2 creeks with nearly identical gradients (Polebridge and Henderson) have mean abundances that are also nearly identical (30.0 and 30.3).

Because Polebridge and Henderson are so close in gradient (0.025 and 0.022), it is possible to consider them as receiving the same treatment when

TABLE 9. Major Habitat Variables of Richland Creek.

	Henderson	Polebridge	Morgan	Laurel
Mean Abundance	30.0	30.3	19.4	10.5
Gradient	0.022	0.025	0.111	0.254
% Pine Coverage	40%	27%	6%	90%
Watershed (Sq. miles)	17.4	9.7	14.9	6.1

compared with the more extreme gradients of the other 2 creeks (0.111 and 0.254). A one-way Anova was conducted with the data from Polebridge and Henderson creeks pooled and compared with the sample data from Laurel and Morgan creeks. This Anova was originally conceived as a comparison of the effect of stream gradient on site abundance of aquatic invertebrates. When compared in this manner, there was a significant effect of the different streams on the abundance of samples collected on a fixed effort basis (Table 10). However, when the data from Polebridge and Henderson creeks was pooled because of common gradient, the data from the 2 streams with moderate amounts of pine coverage were also being pooled. It is therefore not possible to definitely state that the significant effect was the result of stream gradient.

Agreement With Predictions

In the Introduction, 7 predictions or expectations were stated. Based on the information contained in the Results, I shall discuss each of these predictions.

PREDICTION 1. The pH at the mouths of the 4 creeks should vary with the percentage of coverage by pine plantations, so that Laurel Creek with 90% coverage should have the lowest pH, and Morgan Creek with 6% coverage should have the highest pH. Sites on streams in the pine plantations on Walden Ridge should have lower pH values than sites not in pine plantations.

TABLE 10. One-way Anova of effect of stream gradient on abundance.

VARIATION SOURCE	*df*	SS	MS	Fs
Among Streams	2	820.23	410.12	20.44*
Within (error)	19	381.09	20.06	
Total	21	1201.32		
			F(.05)[2,19] = 3.52	

Agreement. The agreement between this prediction and the results was good.

The pH measurements taken at the mouths of the 4 creeks correspond well with the percentage of pine cover. Laurel Creek with 90% coverage by pines always had the lowest pH on any given day measurements were made. Morgan Creek with 6% coverage by pines always either had the highest pH, or a pH equal to the 2 creeks with the intermediate levels of coverage. The pH at the mouth of Morgan Creek was typically slightly basic with an average value of 7.2 for the 4 dates sampled. The pH of Laurel Creek typically was moderately acidic with an average value of 6.0.. Polebridge and Henderson creeks varied from slightly acidic to slightly basic (6.8 to 7.2), with an average value of 7.0 for both creeks.

A one-way Anova was carried out for the pH data from the four creeks (Table 11). The F_S value was significant. We can conclude that there is a significant effect of the percentage of pine plantation coverage of a watershed on the pH of streams draining the watershed, with the pH value declining as the percentage of pine coverage increases.

The comparison of the 7 sites on Walden Ridge that were in pine plantations to the 7 sites not in pine plantations gave results consistent with a lowering of pH by conversion to pine plantations. The average pH for the sites on Morgan Creek (not in pine plantations) was 6.8. The average pH for the 7 sites on Laurel and Henderson

TABLE 11. One-way Anova of the effect of stream pine coverage on pH.

VARIATION SOURCE	*df*	SS	MS	Fs
Among Streams	3	3.57	1.19	23.80*
Within Streams (error)	12	0.58	0.05	
Total	15	4.15		
			F(.05)[3,12] = 3.49	

creeks (in pine plantations) was 5.6. A one-way Anova was carried out for the pH data for the 7 sites in each of these 2 land-use categories (Table 12). The Fs value was significant at the 0.05 level. We can conclude that there is a significant effect of pine plantation coverage of a site, with the pH level of the streams draining sites with pine coverage being lower than sites in nearby land-use sites that contain no pine plantations.

PREDICTION 2. The alkalinity of the 4 branches of Richland Creek should vary with the percentage of coverage by pine plantations in the same manner as the pH. Free carbon dioxide should show an inverse relationship to pH and alkalinity.

Agreement. Agreement between this prediction and the results was good.

Alkalinity measurements made on the same day at the mouths of the lower creeks corresponded positively with pH, so that the creek with the lowest pH always had the lowest alkalinity. The total alkalinity drops as the bicarbonate buffering capacity of the water becomes saturated. Studies from the Adirondacks have shown that once the pH of a stream drops to 6.0, the buffering capacity of the water is ineffective, and acidic precipitation can produce a precipitous drop in pH (Wright and Gjessing, 1976). It is possible therefore, that the low pH value of 5.5 for Laurel Creek does not represent the minimum value for this creek, and a period of acidic deposition could lower the pH even more.

TABLE 12. One-way Anova of the effect of land-use on stream pH.

VARIATION SOURCE	*df*	SS	MS	Fs
Land-Use Type	1	5.04	5.04	53.52*
Within Type (error)	12	1.13	0.09	
Total	13	6.17		
			$F(.05)[1,12] = 4.75$	

Measurements of carbon dioxide at the mouths of the 4 creeks demonstrated the general relationship between pH, total alkalinity, and CO_2. As pH and alkalinity go lower, free CO_2 increases (it is released by a series of buffering reactions). As predicted, Laurel Creek had the highest CO_2 level (50 ppm), and Morgan Creek had the lowest level of CO_2 (12 ppm).

PREDICTION 3. There should be some distribution patterns of aquatic invertebrates that correlate with the amount of coverage of the different creeks by pine plantations.

Agreement. Agreement between this prediction and the results was moderate.

It was my hope that an "indicator" organism would be widely distributed in the sites with neutral pH (low pine coverage) and absent in the sites with acidic pH (high pine coverage). Or the reverse of this situation could apply for a species specialized to the water chemistry of the pine plantation streams.

An organism with an affinity for the chemical conditions of the streams draining the pine plantations should be restricted to upper and lower Laurel Creek and the small branches of Polebridge and Henderson contained in the pine plantations. It would not be present at all in Morgan Creek. On the other hand, an organism adverse to the more extreme conditions of the pine plantation streams would be widely dispersed in Morgan Creek and the small branches of Polebridge and Henderson creeks not in pine plantations, and not present at all in Laurel Creek. It would probably also be distributed in lower Henderson and Polebridge creeks, which were fairly close to Morgan in pH level.

Four species had distributions in the Richland Creek watershed that were a rough fit with the distribution that would be expected for an indicator organism with no affinity for the acidic water chemistry associated with pine coverage. All 4 distributions appear in Figure 7. Two of the species were mayflies of the family Heptageniidae.

Heptagenia sp. had a distribution that fits the pattern of a species with no affinity for the streams in the pine plantations. It was not present in either the upper or lower portions of Laurel Creek, was not present in any of the small streams in the pine plantations on Polebridge and Henderson creeks, and was present in the upper and lower portions of Morgan Creek. Also, this mayfly was present at 3 sites on Polebribge Creek (27% pine coverage) , but only the lowest site on Henderson Creek (39% pine coverage). Unfortunately, *Heptagenia* sp. was only present at a total of 15 sites, so it was not widely dispersed, and it was also only present at 2 of the 15 sites on the portion of Morgan Creek on top of Walden Ridge.

Epeorus dispar, another mayfly of the family Heptageniidae, was present on the portions of Morgan, Polebridge, and Henderson creeks on the escarpment, and also in the main channel of Richland Creek, but absent from Laurel Creek. Unfortunately, this mayfly was present at only one site on Morgan Creek and only a total of 12 sites.

It is likely that these two mayflies of the family Heptageniidae are in fact restricted in their distributions by the acidic conditions of the streams draining the pine plantations. Ephemeroptera are the order of aquatic insects most sensitive in general to acidic pH. Peterson (1989), in a study of 3 stream systems of differing pH, found one species of *Heptagenia* and one species of *Epeorus* that were only rarely collected from the more acidic streams. *Heptagenia* sp. was also absent from riffle

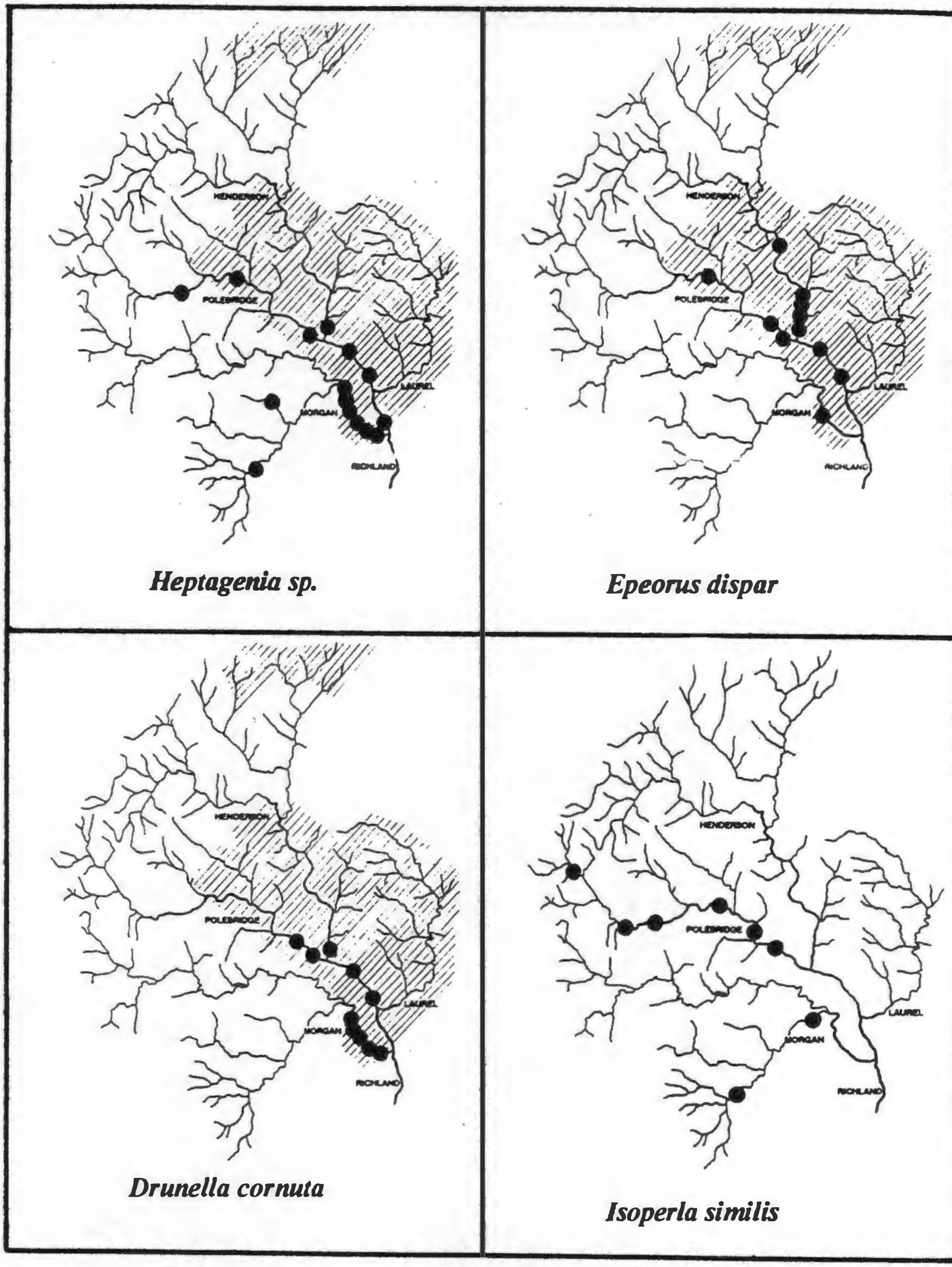

FIGURE 7. Species with distributions that corresponded with stream pH. The shaded area represents pine plantations.

habitats in 20 Canadian streams where the pH was below 6.1 (Clarke and Scruton, 1997). Species of *Heptagenia* have been observed to colonize a river after remediation by liming has raised the pH (Fjellheim and Raddum, 1992). Abundance of *Epeorus* has increased in a stream after liming (Simmons and Doyle, 1996). Increased drift rates and death of larval *Epeorus* has been observed by artificially lowering stream pH to 4.6 (Kratz, Cooper, and Melack, 1994).

The sensitivity of *Epeorus dispar* and *Heptagenia* sp. does not extend to the other 2 commonly occurring members of the family Heptageniidae that were collected in Richland Creek. *Stenacron pallidum* was present at a site in Laurel Creek in the midst of the large pine plantation. *Stenonema sinclairi* was one of the most commonly collected insects on lower Laurel Creek (the creek with the lowest pH). Peterson (1989) found a species of *Stenonema* that was equally distributed in neutral and acidic streams. He also found a species of *Stenonema* that was never present in acidic streams.

Drunella cornuta, a mayfly of the family Ephemerellidae, was present in lower Morgan Creek (5 sites), in Richland Creek (2 sites), and in sites near the mouths of Polebridge and Henderson creeks, but was not present in Laurel Creek. However, this species was present at a total of only 10 sites, so it was not widely distributed.

Again, it is likely that the observed pattern of distribution of *Drunella cornuta* in Richland Creek is a result of the acidic conditions produced in the streams associated with high pine coverage. Increased drift and mortality of *Drunella* sp. has been observed by lowering pH from 6.7 to 4.6 (Kratz, Cooper, and Melack, 1994). Behavior patterns have also been observed to change for a species of

Drunella when the pH was lowered only from 7.8 to 7.0 (Pennuto and Denoyelles, 1993).

The other 2 members of the family Ephemerellidae that were collected in Richland Creek did not have distributions that were restricted by the acidity of the streams. Peterson (1989) found that species of the family Ephemerellidae had differing tolerances for stream pH. *Ephemerella dorothea* and *Eurylophella funeralis*, the other 2 species of Ephemerellidae, were both present in all 4 branches of Richland Creek. In a study of 4 streams of varying pH, *Eurylophella funeralis* was observed to be present at greatest density in the stream with the lowest pH, which was 4.3 (Griffith, Perry, and Perry, 1995). In the same study, *Ephemerella dorothea* was present in greatest density in the stream with the highest pH (7.5). The distributions of *Eurylophella funeralis* and *Ephemerella dorothea* observed in this thesis agree with the results of the study by Griffith, Perry, and Perry. *Ephemerella dorothea* was present at an abundance of 3.8 individuals per site in Morgan Creek (pH 7.2) and 0.7 individuals per site in Laurel Creek (pH 6.0). *Eurylophella funeralis* was present at an abundance of 0.2 individuals per site in Morgan Creek and 1.8 individuals per site in Laurel Creek.

Except for the 3 mayflies, the only species with a distribution that appears to corresponded to stream pH was the stonefly *Isoperla similis* (family Perlodidae). Although this stonefly was only collected at 8 sites, all were in the 2 creeks with the lowest percentage of pine coverage (Morgan and Polebridge). *Isoperla similis* was present both on the top of the ridge, and in the lower portion of Polebridge Creek.

Although stoneflies in general are less sensitive to acidity than mayflies, a species of *Isoperla* was found to occur only in the less acidic of 2 stream systems (Peterson and Van Eeckhaute, 1990). *Isoperla* spp. were also found to increase in abundance with increasing pH (Larsen et al. 1996). However, Simpson et al. (1985) found that *Isoperla* spp. were more dominate in acidic streams.

Isoperla holochlora was found at 13 sites in Richland Creek, only 2 of which were in areas of low pH. The 5 species of stoneflies in the family Perlodidae were collected at a total of 26 sites in areas of higher pH and 6 sites in areas of lower pH.

PREDICTION 4. The sites within the pine plantations on top of Walden Ridge should have lower species richness than the sites on Walden Ridge not in pine plantations. The species richness on the portion of Laurel Creek (90% coverage of the upstream watershed by pine plantations) that descends the escarpment should be lower than the species richness of the portion of Morgan Creek that descends the escarpment (6% coverage of the upstream watershed by pine plantations).

Agreement. Agreement between this prediction and the results was mixed.

For the sites on Walden Ridge that were either in or not in pine plantations, the 7 sites in the plantations had a total species richness of 17, compared with 28 for the 7 sites not in pine plantations. Figure 8 shows this richness broken down into richness of the different orders of aquatic insects. When compared to the sites not in pine plantations, the sites in the pine plantations had less species in every order except for the Diptera. When compared in a two-way Anova without replication (Table 13), the differences in the richness of the orders was significant. There are several reasons to attribute this significant difference in richness to coverage of sites by pine plantations. First, the lower richness in the pine plantations agrees with the generally observed trend from other animal studies (Langley and Shure, 1980), (Mitchell et al. 1997), (Niemela, Langor, and Spence, 1993), (Repenning and Labisky, 1985), (White et al. 1996). Also, the measured pH of the stream sites in the

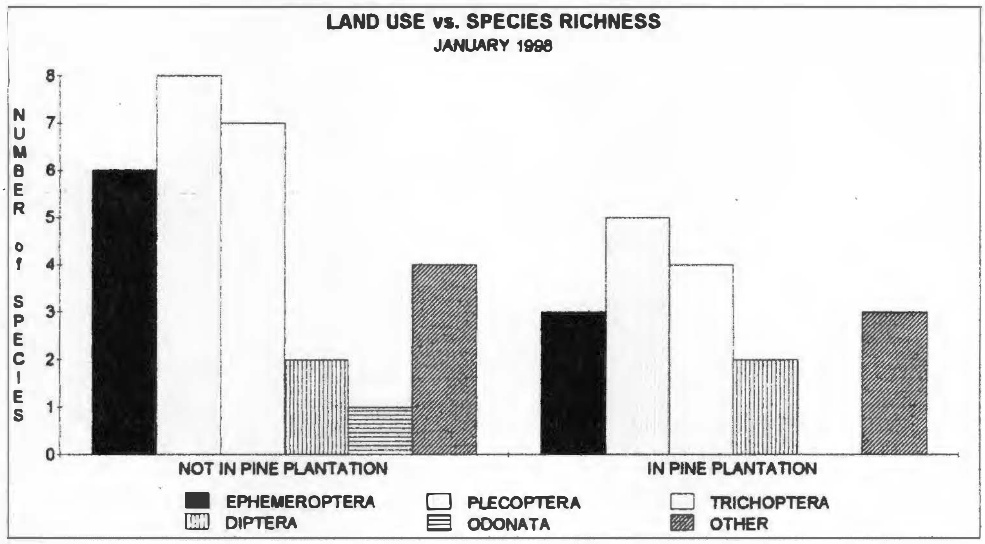

FIGURE 8. Bar graphs of richness of orders for 2 classes of land-use.

TABLE 13. Two-way Anova without replication of effects of pine coverage and insect orders on species richness of land-use types.

VARIATION SOURCE	*df*	SS	MS	Fs
Insect Orders	5	49.75	9.95	11.26*
Pine Coverage	1	10.08	10.08	11.42*
Error	5	4.42	0.88	
Total	11	64.25		
	F(.05)[5,5] = 5.05		F(.05)[1,5] = 6.61	

pine plantations was significantly lower than the pH of the sites not in the pine plantations. Finally, there were the 3 species of mayflies that were observed to have distributions that corresponded to stream acidity, which in the case of the Richland Creek system, is a reflection of the amount of coverage by pine plantations.

Interestingly, when the richness of the individual sites in and not in pine plantations was compared (instead of the richness of the combined 7 sites in each category) in a one-way Anova (Table 14), there was no significant effect from pine coverage. The mean value for the pine plantation sites was 5.5 species per site, compared to a value of 7.0 for the sites not in pine plantations. Apparently, there is greater similarity between sites in the pine monoculture, compared to the more diverse land-use category that is not in the plantations.

The species richness was also compared for the 100-foot elevation sites on the lower portion of the 4 creeks. Table 15 shows the species richness of these sites for the winter, spring, and combined winter-spring sampling periods. Because Laurel Creek had a much higher percentage of pine coverage than the other 3 creeks (and also lower pH), I thought that it would have the lowest richness, as did the sites in the pine plantations on the upper creek. Laurel Creek did have the lowest number of species for the winter sampling, but had the highest species richness for the spring,

TABLE 14. One-way Anova of effect of pine coverage on individual site richness.

VARIATION SOURCE	*df*	SS	MS	Fs
Pine Effect	1	8.64	8.64	2.37
Within	12	43.71	3.64	
Total	13	52.36		
			$F(.05)[1,12] = 4.75$	

TABLE 15. Species richness of the 4 creeks and 2 land-use categories.

	Morgan	lebrid	Henderson	Laurel	in pines	not in pines
% Pine	6%	27%	39%	90%	100%	0%
SPECIES RICHNESS						
winter	12	10	13	9		
spring	15	16	16	17		
total	22	21	23	22	17	28

and the total richness for the winter and spring combined for Laurel Creek was in the middle. Overall species richness for the 4 lower creeks was in a very narrow range (21 to 23) for the sampling period.

As mentioned before, the lower portions of the 4 creeks are in canyons that contain a mix of mainly deciduous trees (they are not in pine plantations). Thus lower Laurel Creek has altered water chemistry from the presence of pine plantations on the upper watershed, but is not surrounded by a monoculture. Lower Laurel Creek is better viewed as a waterway with altered pH than as a stream contained within a pine plantation. The lower portion of this creek could then be expected to show the effects observed from studies of acidic deposition or of streams naturally low in pH. In this regard, the overall richness would not be expected to be significantly lower, but the richness of the orders might be different when Laurel Creek is compared to the other three creeks. Specifically, richness of the order most sensitive to pH (Ephemeroptera) was expected to be lowest on Laurel Creek (Peterson and Eeckhaute, 1992), and the least sensitive order (Plecoptera) was expected to be highest on Laurel Creek (Griffith, Perry, and Perry, 1993). Figure 9 shows a comparison of the lower portions of the 4 creeks with the species richness broken down into richness of the orders. Laurel Creek, with the highest percentage coverage by pine plantations, did have less species of mayflies than any of the other 3 creeks.

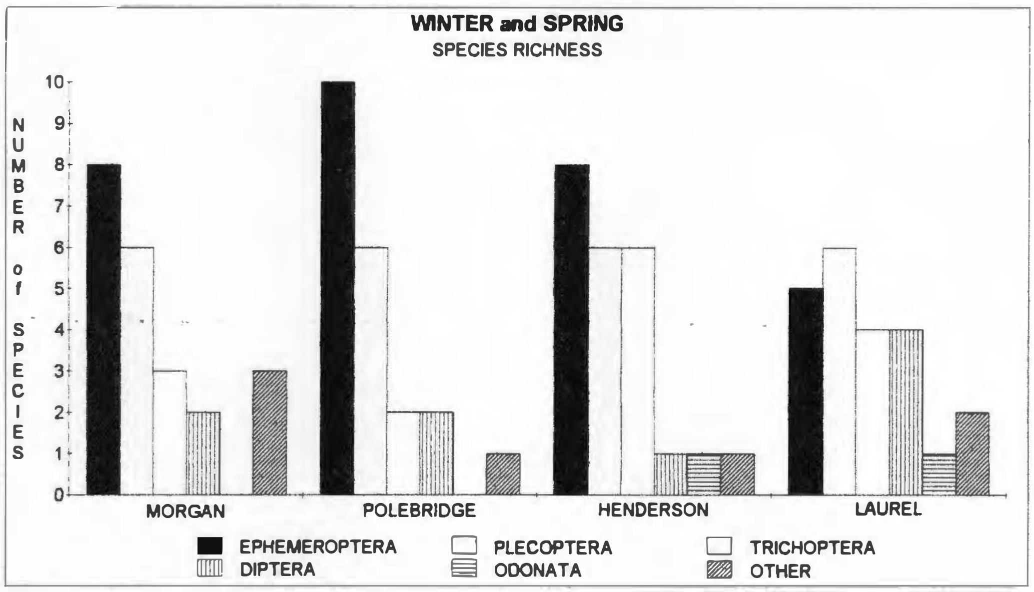

FIGURE 9. Bar graphs comparing richness of the insect orders of the 4 creeks.

The stonefly richness was not higher on Laurel Creek, but was constant at 6 species for the 4 creeks. Laurel Creek also had a higher number of Diptera species than the other 3 creeks.

The lower richness of mayflies on Laurel Creek is mainly due to the exclusion of the three acidic pH sensitive species (*Drunella cornuta*, *Epeorus dispar*, and *Heptagenia* sp.). Based strictly on these bar graphs, the community composition of the creeks agreed with our expectations for mayflies (but not for stoneflies). Laurel Creek, with the lowest pH had the fewest number of mayfly species. Unfortunately, there is no statistical evidence for the significance of the difference in mayfly richness. Because total mayfly richness for any individual creek is a cumulative figure that is not directly based on the mayfly richness of the individual sites in the creek, an Anova comparing the mayfly richness of the various individual sites on 2 creeks would not be the same as comparing overall mayfly richness of the entire creek. In fact, the mean number of mayfly species per sampling site for the spring sampling period was higher for Laurel Creek (3.2) than for Morgan Creek (2.7). Morgan Creek is the creek with the lowest coverage by pine plantations, and the highest pH. Apparently, the elimination of the more acid-sensitive species of mayflies (*Heptagenia* sp., *Epeorus dispar*, and *Drunella cornuta*) from Laurel Creek resulted in lower mayfly richness even though the more acid-tolerant species of mayflies were widely distributed over the sites in the creek.

PREDICTION 5. There should be differences in community composition and diversity related to the amount of pine plantation coverage of the 4 streams.

Agreement. Agreement between this prediction and the results was low.

The 4 measurements of community composition used were EPT richness, the Shannon diversity index, the Jaccard coefficient of community similarity, and the relative abundances of the insect orders of the four creeks.

In general, Laurel Creek had the community least like the others by the 4 measurements. However, it was not possible in most cases to directly relate these differences in community structure to the 2 land-use categories. As mentioned at the beginning of the Discussion section, the difficulty in analysis is that the creek with the highest coverage by pine plantations (Laurel Creek) also is the smallest in drainage area, and has a steeper gradient than the other 3 creeks. For the comparison of the land-use categories on the top of Walden Ridge it was possible to minimize size and gradient differences by careful selection of sampling sites, so differences there could be attributed to land-use alone.

EPT richness (i.e., richness of Ephemeroptera, Plecoptera, and Trichoptera), is commonly used to access environmental differences between communities (Merrit and Cummins, 1996). This measure is based on the concept that these 3 orders are more environmentally sensitive than other orders. Table 16 shows the EPT data for both the sites on the escarpment, and the sites on the Ridge that were in or not in pine plantations.

For the lower portion of the 4 creeks the EPT values correlated with stream gradient instead of amount of pine coverage. The 2 creeks with the lowest gradient (Polebridge and Henderson) had the highest EPT richness (18 and 20), and the creek with the highest gradient (Laurel) had the lowest value (15).

The EPT values were also calculated for the sites that were either in or not in pine plantations (Table 16). The sites not in pine plantations had 21 EPT species out of a total of 28 species, compared with 12 EPT species out of a total of 17 for the sites in the pine plantations.

When the EPT richness of the 7 individual sites in each of the 2 land-use categories were compared in a one-way Anova, there was no significant effect observed from the differences in pine coverage at the 0.05 level (Table 17).

However, because the EPT richness of the two land categories is a cumulative value, each individual site may or may not add a new EPT species. This is the same argument that was made when comparing the species richness of the 2 land-use categories. To compare the EPT values for the 2 land-use categories, a two-way Anova without replication was conducted with the two land-use categories as the rows and the three EPT orders as the columns. This data is simply a sub-set of the data used to compare overall species richness of the 2 land-use categories. The Anova comparing the EPT richness of the land-use categories (Table 18) resulted in a significant Fs value for the effect of pine coverage on EPT richness.

TABLE 16. Richness of mayflies, stoneflies, and caddisflies (EPT).

	Morgan	Polebridge	Henderson	Laurel	in pines	not in pine
total number species	22	21	23	22	17	28
number EPT species	17	18	20	15	12	21
EPT/total number	0.77	0.86	0.87	0.68	0.71	0.75

TABLE 17. One-way Anova of effect of pine coverage on site EPT richness.

VARIATION SOURCE	*df*	SS	MS	Fs
Pine Coverage	1	12.07	12.07	3.50
Within (error)	12	41.43	3.45	
Total	13	53.50		
			F(.05)[1,12] = 4.75	

TABLE 18. Two-way Anova without replication of the effects of pine coverage and insect orders on species richness of EPT orders.

VARIATION SOURCE	*df*	SS	MS	Fs
Insect Orders	2	7.00	3.50	20.59*
Pine Coverage	1	16.67	16.67	98.05*
Error	2	0.33	0.17	
Total	5	24.00	4.80	
	F(.05)[1,2] = 18.5		F(.05)[2,2] = 19.0	

Because the sites in pines or not in pines are generally similar in stream size and gradient, it is possible to attribute the differences in EPT richness between these sites to the differences in land-use. For the land-use categories the effect of altered water chemistry and, possibly, the effect of the pine monoculture are resulting in lower EPT richness in the pine plantations than in the areas not in the pine plantations.

The Shannon Diversity Index was calculated for the portions of Morgan and Laurel creeks on the escarpment (the 100-foot elevation sites), and for the 14 sites on the top of Walden Ridge that were either in or not in pine plantations (Table 19). For the sites on lower Morgan and Laurel creeks, the abundances of the species were determined by a combined count of the winter and spring samplings. For the sites in pines or not in pines, the abundances of the species was determined from the single

TABLE 19. Comparisons of Shannon Index values and results of *t*-test.

	SHANNON INDEX
In Pines	**2.29**
Not In Pines	**2.69**
calculated t value:	2.34*
table t value: (0.05 significance level)	2.03
DF = 36	
MORGAN (lower)	**2.47**
LAUREL (lower)	**2.52**
calculated t value:	0.29
table t value: (0.05 significance level)	2.01
DF = 45	

winter sampling of the 14 sites in the 2 land-use categories.

The Student's *t*-test was used to determine if there was a significant difference in the Shannon indices of the two land-use categories and in the Shannon indices of the lower portions of Morgan and Laurel creeks. This use of the *t*-test is discussed in the Methods section of this thesis, and is based on a method developed by Hutcheson (1970). For the sites on lower Morgan and Laurel creeks (the 2 creeks with the lowest and highest pine coverage), there was no significant difference in the Shannon indices of the two communities. There was a significant difference in the diversity of the sites in pines compared to the sites not in pines at the 0.05 level of significance (although it was not significant at the 0.02 level). We can conclude that the combined sites in the pine plantations are slightly less diverse than the combined sites not in pine plantations when compared by the Shannon Diversity Index. It should be noted that the four calculated Shannon Indexes only ranged from 2.29 to 2.69. Real community values for the Shannon Index tend to range from 1.0 to 6.0 (Stiling, 1996), so all 4 of our values fell within a very narrow range.

<u>The Jaccard Coefficient of Community Similarity</u> was calculated from the data in Table 20 for the sites on the lower portion of the 4 creeks. Table 21 gives the values of the Jaccard coefficient for a pair-wise comparison of all 4 creeks. This comparison generally agrees with what we would expect from the absence of acid-sensitive mayflies from Laurel Creek, and from the higher number of species of Diptera in Laurel than in the other 3 creeks. Laurel Creek is less similar to the other 3 creeks than the other 3 creeks are to each other. As stated earlier, while it is convenient to attribute the lower similarity of Laurel Creek to lowered pH due to pine coverage, it is also possible that stream size and/or gradient could be contributing factors.

TABLE 20. Species richness and species in common for the 4 creeks.

	Morgan	Polebridge	Henderson	Laurel
species in lower creek	30	22	25	25
species in entire creek	49	25	31	36
	species in common on lower creeks			
Morgan		19	21	18
Polebridge	19		17	15
Henderson	21	17		15
Laurel	18	15	15	

TABLE 21. Jaccard Coefficient of similarity for 4 creeks.

	Morgan	Polebridge	Henderson	Laurel
Morgan		58%	62%	49%
Polebridge	58%		57%	47%
Henderson	62%	57%		43%
Laurel	49%	47%	43%	

<u>Relative Abundance</u> was calculated for the 100-foot elevation sites on the sides of Walden Ridge, and for the sites in or not in pine plantations on the top of the ridge. This data appears in Figures 10 and 11.

For the sites either in or not in pine plantations, the differences in the graphs for the 2 land-use categories are essentially due to the higher value of relative abundance for the Diptera larvae in the sites in the pine plantations. The abundance of Diptera was compared in a one-way Anova for the 14 sites either in or not in pine plantations (Table 22). There was a significant effect of pine coverage on the abundance of Diptera larvae. We can conclude that the sites on the streams in pine plantations had a higher abundance of Diptera due to the sites being located in a pine plantation, instead of in nearby areas of mixed land-use that did not include pine plantations.

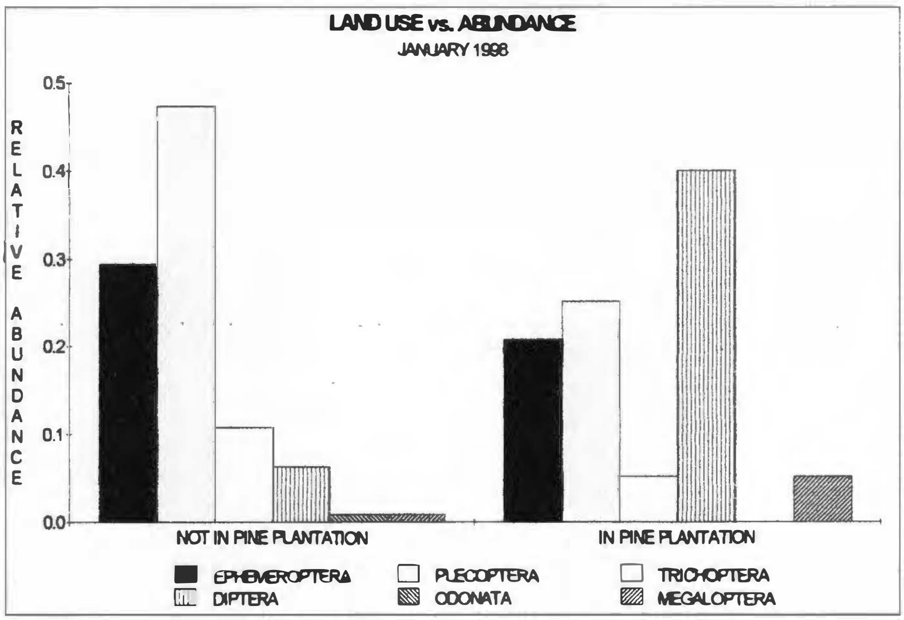

FIGURE 10. Graphical relationship between pine coverage and abundance.

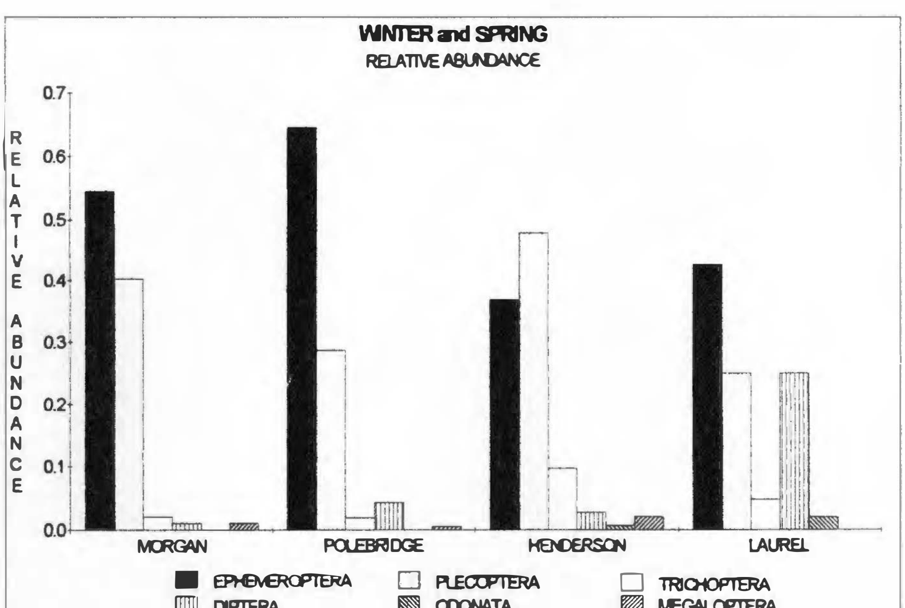

FIGURE 11. Graphical relationship between the 4 creeks and abundance.

TABLE 22. One-way Anova of the effect of pine coverage of small streams on Diptera abundance.

VARIATION SOURCE	*df*	SS	MS	Fs
Pine Coverage	1	37.79	37.79	5.36*
Within Groups (error)	12	84.57	7.05	
Total	13	122.36		
			$F(.05)[1,12] = 4.75$	

In the graphs for the 4 creeks, Laurel Creek (with 90% pine coverage) had a higher value of relative abundance for Diptera than the other 3 creeks. The abundance of Diptera in the 100-foot elevation sites of Laurel Creek and Morgan Creek was compared in a one-way Anova (Table 23). Laurel and Morgan creeks were compared because they had the highest and lowest pH values, and also because they were close in gradient. The Fs value from this Anova was not significant at the $\alpha = 0.05$ level.

Studies of streams with a range of pH values generally indicate that Diptera are a major faunal component in all streams sampled. Specifically, black flies (Simuliidae) are a common constituent of acidic streams (Simpson, Bode, and Colquhoun, 1985). It was the black fly *Prosimulium mixtum* that accounted for most of the increased abundance on lower Laurel Creek and in the sites in the pine plantations.

Overall, the measurements of community composition demonstrate that lower species richness, lower EPT species levels, and an increase in dipteran abundance occurs at the sites in pine plantations when they are compared to nearby sites of mixed land-use that does not include pine plantations.

Because the sites either in or not in pine plantations on the top of Walden Ridge minimize gradient and stream size as factors influencing community structure,

TABLE 23. One-way Anova of the effect of the amount of pine coverage of Laurel and Morgan creeks on Diptera abundance.

VARIATION SOURCE	*df*	SS	MS	Fs
Among Streams	1	33.33	33.33	1.00
Within streams (error)	10	332.67	33.27	
Total	11	366.00		
			$F_{(.05)[1,10]} = 4.96$	

the differences in these communities can be attributed to land-use alone. When the differences between lower Laurel Creek and the other 3 lower creeks resemble the differences between the creeks in the 2 land-use sites on the top of Walden Ridge, it is convenient to infer that the differences in the lower creeks are also due to land-use. This inference is strengthened by the measured differences in stream chemistry of the lower creeks, which are certainly caused by the land-use on Walden Ridge. However, it should always be remembered that the drainage areas and gradients of the 4 lower creeks are also factors of influence on community structure that vary widely.

The comparison of the lower portion of Laurel Creek to the lower portion of the other 3 creeks indicates that there is little difference in overall species richness or community diversity. Several species of acid-sensitive mayflies are excluded from Laurel Creek, so mayfly richness is lower on that creek. Observed Diptera richness was higher for Laurel Creek than the other 3 creeks, but the difference was not significant. The Jaccard coefficient of community similarity indicated that Laurel Creek is less similar to the other 3 creeks than they are similar to each other.

PREDICTION 6. There should be some specialized species restricted either to the high-energy and higher-order canyons of the escarpment, or to the less energetic and lower-order tributaries of the 4 branches on the top of Walden Ridge.

Agreement. Agreement with this prediction was good.

There were 10 species that were present primarily on the higher-order, more energetic streams of the escarpment (the lower portion of the streams), and 4 species that were present primarily on the lower-order lower-energy tributaries on the top of Walden Ridge (Table 24).

Of the 8 species of mayflies that were restricted to either the upper or lower creeks, all 8 were restricted to the lower creeks.

Only 2 species of caddisflies were restricted, both to the upper creeks. It is likely that the bulky nature of the cases of these species (*Ironoquia punctatissima* and *Playtocentropus radiatus*) would restrict them from the higher-energy portions of the streams.

Psephenus herricki, the "water penny" of the family Psephenidae (order Coleoptera), was restricted to the higher-order lower portion of the Richland Creek system.

Of the species of stoneflies that were restricted to the upper or lower creeks, 3 were restricted to the lower creeks and 2 to the upper creeks.

Leuctra sp., a stonefly of the family Leuctridae, was confined to the lower portion of the system.

Isoperla holochlora, a stonefly of the family perlodidae, was confined to the lower portion of the system. Three other stoneflies of the family Perlodidae were mainly confined to the upper part of the system on top of Walden Ridge. These 4 were: *Cultus decisus*, *Diploperla duplicata*, and *Clioperla clio*.

Acroneuria carolinensis, *Acroneuria abnormis*, and *Acroneuria lycorias*, 3 stoneflies of the family Perlidae, were confined to the lower portion of the Richland Creek system, except for one site at 1700 feet on Laurel Creek.

TABLE 24. Species restricted to the upper or lower portion of the Richland Creek system of creeks.

SPECIES	UPPER	LOWER
EPHEMEROPTERA		
BAETIDAE (3 species)	1	**21**
HEPTAGENIIDAE		
Epeorus dispar	0	**12**
Stenonema sinclairi	0	**11**
ISONYCHIIDAE		
Isonychia sp.	0	**4**
EPHEMERELLIDAE		
Drunella cornuta	0	**10**
Ephemerella dorothea	0	**16**
PLECOPTERA		
LEUCTRIDAE		
Leuctra sp.	0	**9**
PERLODIDAE		
Isoperla holochlora	0	**14**
Clioperla clio	**6**	0
Cultus decisus	**4**	0
PERLIDAE		
Acroneuria spp.	1	**16**
TRICHOPTERA		
LIMNEPHILIDAE		
Ironoquia punctatissima	**3**	0
Playtocentropus radiatus	**3**	0
COLEOPTERA		
PSEPHENIDAE		
Psephenus herricki	0	**7**

Except for *Isoperla holochlora,* there was no overlap between the ranges of stoneflies of the family Perlidae and the family Perlodidae (Figure 12). The Perlidae, except for 2 sites, were confined to the lower portion of the system. Except for *Isoperla holochlora*, the Perlodidae were generally confined to the upper portion of Walden Ridge. If viewed on a seasonal basis, the separation of the Perlidae and Perlodidae stoneflies is even more apparent. In the winter sampling period *Isoperla holochlora* was only collected at 2 sites, so in that season range overlap of the 2 stonefly families was limited to those 2 sites.

Sheldon (1985) studied the distribution of the perlid stoneflies in the Little River drainage of the Great Smoky Mountains National Park. He correlated the distribution of these stoneflies with both elevation and stream size. *Acroneuria abnormis* had the greatest habitat amplitude of the 5 species studied, occurring from the smallest streams studied to the largest, and occurring from 300 meters elevation to 1300 meters.

Based on Sheldon's study, we could expect *Acroneuria abnormis* to cover most of our study area, instead of apparently being confined to the lower portions of the stream. Sheldon's study would seem to eliminate elevation and stream size as the factors excluding this stonefly from the top of Walden Ridge, so we are left with stream gradient as the probable cause. Unlike the Great Smoky Mountains where the smaller streams are likely to occur on the steepest gradients, the smaller upper streams of the Richland Creek system are on the low gradient of Walden Ridge.

The restriction of *Acroneuria* spp. to the lower portion of the streams has resulted in a partitioning of the streams by the 2 families of large predatory stoneflies into a lower portion dominated by species of Perlidae and an upper portion dominated by species of Perlodidae.

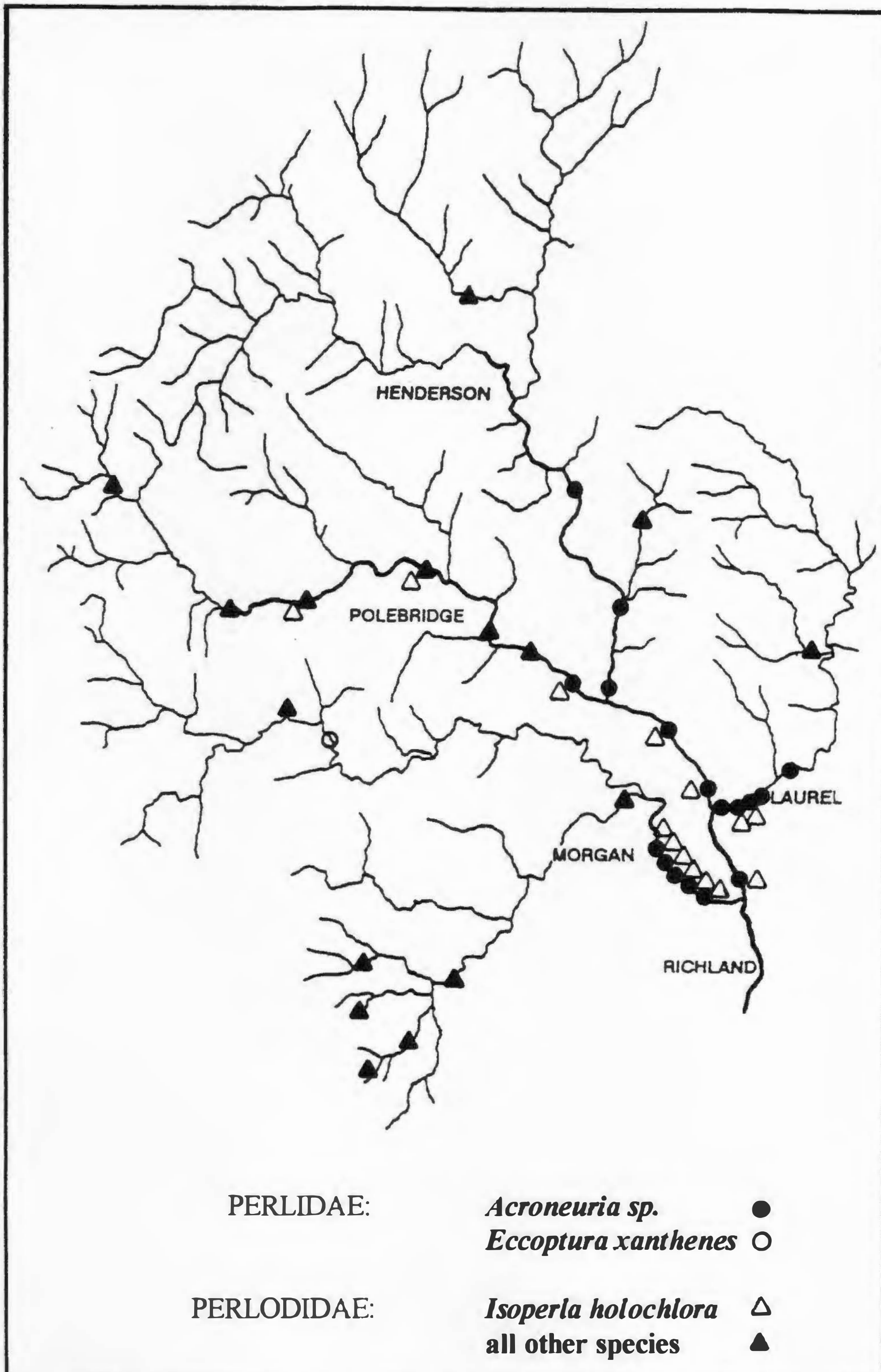

FIGURE 12. Distribution of two families of stoneflies. Except for *Isoperla holochlora*, there was no overlap in the ranges of the two families.

PREDICTION 7. Some species should exhibit seasonal patterns of abundance.

Agreement. Agreement between this prediction and the results was good. The 100-foot sites on the escarpment were all sampled both in the winter (12/97 to 1/98) and the spring (4/98 to 5/98). There were 3 mayflies with distributions that were restricted to one of these 2 time periods. The 3, *Heptagenia* sp., *Drunella cornuta,* and *Ephemerella dorothea* were all restricted to the spring sampling (Table 26).

The mayflies were the most seasonal of the orders, with the majority of species either occurring entirely in the spring, or having higher abundance in the spring than in the winter. Of all mayflies sampled, only 2 were present at more winter sites than spring sites. *Ameletus lineatus* (Siphlonuridae) was present at 12 winter sites and 10 spring sites. *Eurylophella funeralis* (Ephemerellidae) was present at 8 winter sites and 6 spring sites.

TABLE 25. Species with larvae restricted to one of the 2 sampling periods.

	WINTER # sites	SPRING # sites
ORDER EPHEMEROPTERA		
HEPTAGENIIDAE		
Heptagenia sp.	0	**15**
EPHEMERELLIDAE		
Drunella cornuta	0	**10**
Ephemerella dorothea	0	**16**
ORDER PLECOPTERA		
NEMOURIDAE		
Amphinemura nigritta/delosa	0	**8**
TAENIOPTERYGIDAE		
Oemopteryx contorta	**20**	0
Taeniopteryx sp.	**37**	0

There were 3 stoneflies that were restricted to one of the 2 seasons sampled. *Amphinemura nigritta/delosa* was restricted to the spring sampling. *Oemopteryx contorta* and *Taeniopteryx* sp. were restricted to the winter sampling period.

The restriction of the highly abundant *Oemopteryx contorta* and *Taeniopteryx* sp. to the winter and of most mayflies to the spring implies that food and habitat resources are being partitioned by time. Merrit and Cummins (1996) list the feeding habits of *Taeniopteryx* as shredders-detritivores, facultative collectors-gatherers (scrapers). *Ephemerella* mayflies are listed as collectors-gatherers, scrapers. *Drunella* are classified as scrapers. *Heptagenia* are listed as scrapers, collectors, gatherers. Both species of stoneflies and all three species of mayflies are classified as clingers. The similar trophic and habit classifications of the seasonal mayflies and stoneflies support the proposition that resources in the streams as being partitioned in time by these two groups.

The species richness of the lower portion of the 4 creeks was broken down into richness of orders for the winter and spring sampling (Figures 13 and 14). These graphs demonstrate the effects of the seasonal species on community composition.

The stoneflies (with two common species restricted to the winter) have the highest number of species on one creek (Laurel) in the winter, and a number equal to the mayflies on Henderson. In the spring, when there are 3 species of seasonal mayflies present, the mayflies have the highest number of species on all 4 creeks.

When the winter and spring graphs of relative abundance are considered (Figures 15 and 16), again the influence of the seasonal species is apparent. The stoneflies are dominant on all 4 creeks in the winter, due to the seasonal presence of 2 common species. The mayflies are the most abundant on all 4 creeks in the spring when 3 common seasonal species are present.

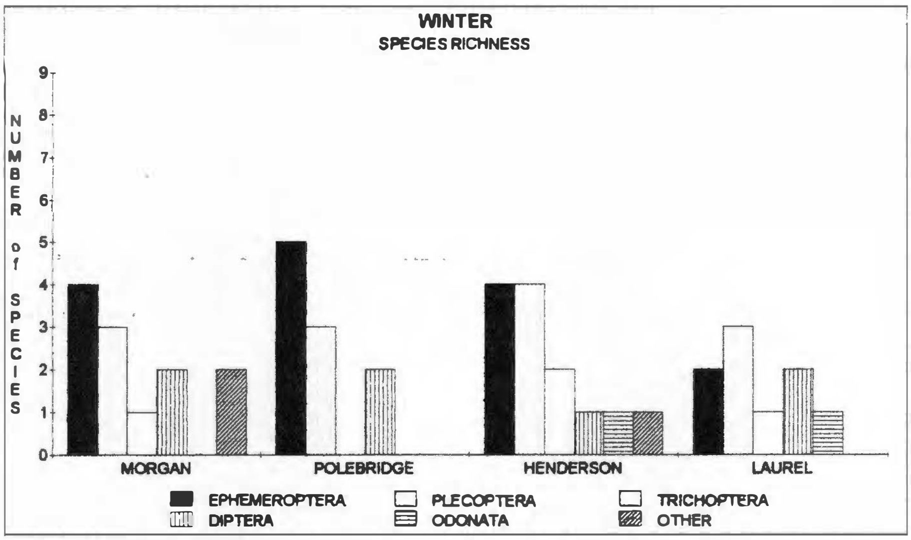

FIGURE 13. Species richness of the lower creeks for 12/97 to 1/98.

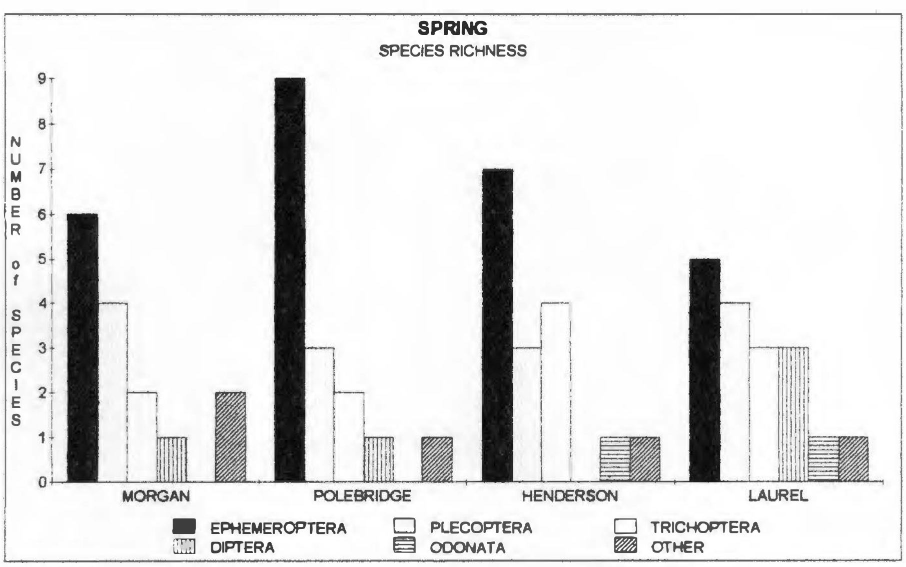

FIGURE 14. Species richness of the lower creeks for 4/98 to 5/98.

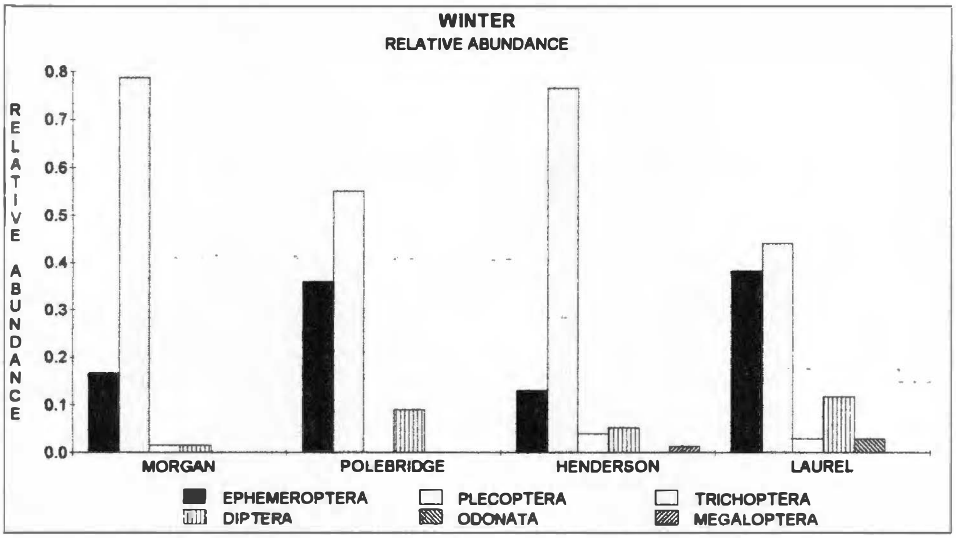

FIGURE 15. Relative Abundance on the four lower creeks for 12/97 to 1/98.

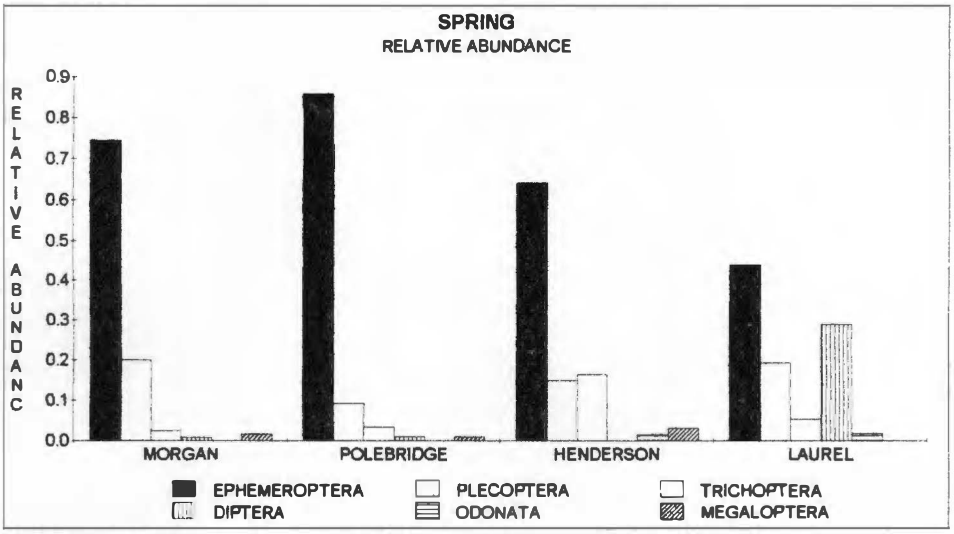

FIGURE 16. Relative Abundance on the 4 lower creeks for 4/98 to 5/98.

Pine Plantations

It was one goal of this study to look for downstream differences in community composition that reflected the upstream land use patterns (percentage of coverage by pine plantations). In this regard, it was expected that Laurel Creek (with 90% coverage) would be unique when compared with the other 3 creeks. While there were differences in the downstream community composition, they were not as profound as might be expected from the differences in water chemistry.

Laurel Creek was less similar to the other 3 creeks than they were to each other when measured by the Jaccard coefficient of community similarity, but there were no widespread species present in Laurel Creek that were not present in the other 3 creeks. There were 3 species of mayflies (*Drunella cornuta*, *Epeorus dispar*, and *Heptagenia* sp.) that were widespread in the other 3 creeks, but absent from Laurel Creek. Based on the results of this thesis, and of other studies, it is likely that these 3 mayflies are being excluded from Laurel creek by the acidic pH of that creek. Besides the lower mayfly richness, about the only statement that can be made about the downstream differences between high pine coverage and low pine coverage is that Diptera species appear to have more importance in the stream with highest pine coverage (Laurel), with both relative abundance and richness of Diptera being higher in that creek than the other 3 creeks. However, the differences in the Diptera larvae in the bar graphs of abundance for the lower portion of the 4 creeks did not prove to be significant.

In regard to water chemistry, the downstream differences were easy to demonstrate. Measurements demonstrated the expected results: that pH and alkalinity were negatively correlated with pine coverage. There was a small but consistently measurable difference in the pH and alkalinity between Morgan Creek with 6% coverage and Polebridge Creek with 27% coverage. The buffering capacity of Laurel Creek was nearly depleted, with a low of pH 5.0 being measured on the lower portion of that creek. Generally, the pH of a stream has to drop to pH 5.0 or lower for an extended period before serious degradation of the aquatic invertebrate community occurs (Simpson, Bode, and Colquhoun, 1985).

Differences in the 2 land-use categories on top of Walden Ridge were easier to measure than downstream differences on the 4 creeks. When the sites in the pine plantations were compared to the sites not in the pine plantations, there was a significant difference in the number of species present, with the sites in the plantations having fewer species (17 compared to 28). The EPT species index was also significantly lower. The abundance of Diptera was significantly higher in the pine plantation sites. The difference in diversity of the 2 land-use types as measured by the Shannon Index was marginally significant, with the pine plantation sites having the lower Shannon index value. The 3 acid sensitive mayflies were absent from the pine plantations, but no mayfly was so widespread in the sites outside the pine plantations that it could be called an indicator organism. Perhaps more interesting was the lack of any specialized widespread species that was restricted to the pine plantations. Mayflies, stoneflies, and caddisflies were well represented in the sites in pine plantations, but by fewer species than in the sites not in pine plantations.

One stonefly that was found at 2 sites in the pine plantations was *Allocapnia* sp. Ross and Ricker (1971) indicated that species of *Allocapnia* are generally restricted to high quality streams in deciduous forests. It is interesting in this respect, that 2 of the 3 sites where these winter stoneflies were collected in the Richland Creek watershed were in small streams contained within the pine plantations.

Most streams inside the pine plantations tend to be surrounded by a narrow belt of deciduous trees. This was true of the sites where *Allocapnia* sp. were collected. Ross and Ricker (1971) state that the few species of *Allocapnia* that extend into the northern coniferous forest occur in areas where there is a local abundance of deciduous trees. The network of deciduous trees along the streams is probably a factor that helps maintain aquatic insect diversity in the pine plantations.

While measured community diversity of aquatic invertebrates was lower in the pine plantations of this study, it should be noted that there are some features of the pine plantations that favor overall community diversity on Walden Ridge. Walden Ridge is an area that is undergoing rapid human population increase, with an associated increase in activities that degrade water quality (increased use of pesticides, cattle grazing, hog farms, large-scale chicken farming, and clearing of forests). In sharp contrast to this increasing human activity are the pine plantations, where human activity is essentially restricted to tree harvesting and deer hunting. In the present climate of rapid development, the pine plantations offer one of the most stable environments on Walden Ridge. Moreover, the size of the contiguous pine plantations argues for the presence of species requiring large unfragmented habitats. The pine plantations on the creeks of this study are at the southern end of a plantation that extends nearly 8 miles to the north.

6. CONCLUSIONS

Stream Chemistry

The pH and total alkalinity measurements at the mouths of the creeks in this study were inversely correlated with the amount of upstream coverage of the drainages by pine plantations on Walden Ridge. A creek with low pine coverage (6%) was near neutral in pH, while a creek with high pine coverage (90%) was moderately acidic.

The pH and total alkalinity measurements at stream sites contained within pine plantations were lower than pH and alkalinity measurements made in sites outside the pine plantations.

Effects of Pine Plantation Coverage

UPSTREAM SITES: The differences in pine coverage on Walden Ridge resulted in significant differences in the invertebrate communities in the streams on Walden Ridge that were in pine plantations, when compared to nearby sites in mixed land-use areas (no pine plantations). In the pine plantations there was lower species richness, lower EPT richness, less Ephemeroptera species, and a greater abundance of dipterans.

DOWNSTREAM SITES: While the water chemistry downstream from the pine plantations was modified, the invertebrate community did not demonstrate as many changes as occurred on the portions of the streams inside the pine plantations. Three species of mayflies (*Drunella cornuta*, *Epeorus dispar*, and *Heptagenia* sp.) were identified that were excluded from the creek with the lowest pH (Laurel

Creek). Abundance and richness of Diptera were higher in Laurel Creek than in the other 3 creeks, but not to a significant level. The Jaccard index of similarity indicated that Laurel Creek was less similar to the other 3 creeks than they were similar to each other. Factors such as stream gradient and watershed size may have contributed to the observed differences between Laurel Creek and the other 3 creeks.

Distributions of Insects

UPPER AND LOWER CREEKS: *Acroneuria* stoneflies of the order Perlidae were restricted to the lower high-gradient portions of the four creeks, and had no range overlap with stoneflies of the order Perlodidae, except for *Isoperla holochlora*. The absence of *Acroneuria* stoneflies from the top of Walden Ridge was attributed to the low gradient of the streams on the Ridge.

SEASONAL DISTRIBUTIONS: Seasonal differences in mayflies and stoneflies resulted in the stoneflies having the highest abundance on all four creeks in the winter, and in the mayflies having the highest abundance in the spring on all four creeks. Species richness was higher in the spring than in the winter on all 4 creeks.

The Study Design

At the time that this study was proposed, I was unaware of both the exact percentage of coverage by pine plantations of the 4 branches of Richland Creek and of the lack of research on the aquatic insect communities within pine plantations.

Laurel Creek with 90% pine plantation coverage and Morgan Creek with 6% coverage made a good pair for comparison of creeks with low coverage and high coverage. However, Polebridge and Henderson creeks with 26% and 39% pine plantation coverage added little useful information to this study. Unfortunately, these 2 creeks were much more time consuming to sample because of a lack of good access points and greater stream length due to their low gradients.

In retrospect, more useful information could have been gathered with the same amount of effort by leaving Polebridge and Henderson creeks out of this study, and instead devoting the time to sampling an increased number of sites on the top of Walden Ridge that were either in or not in pine plantations.

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APPENDIX

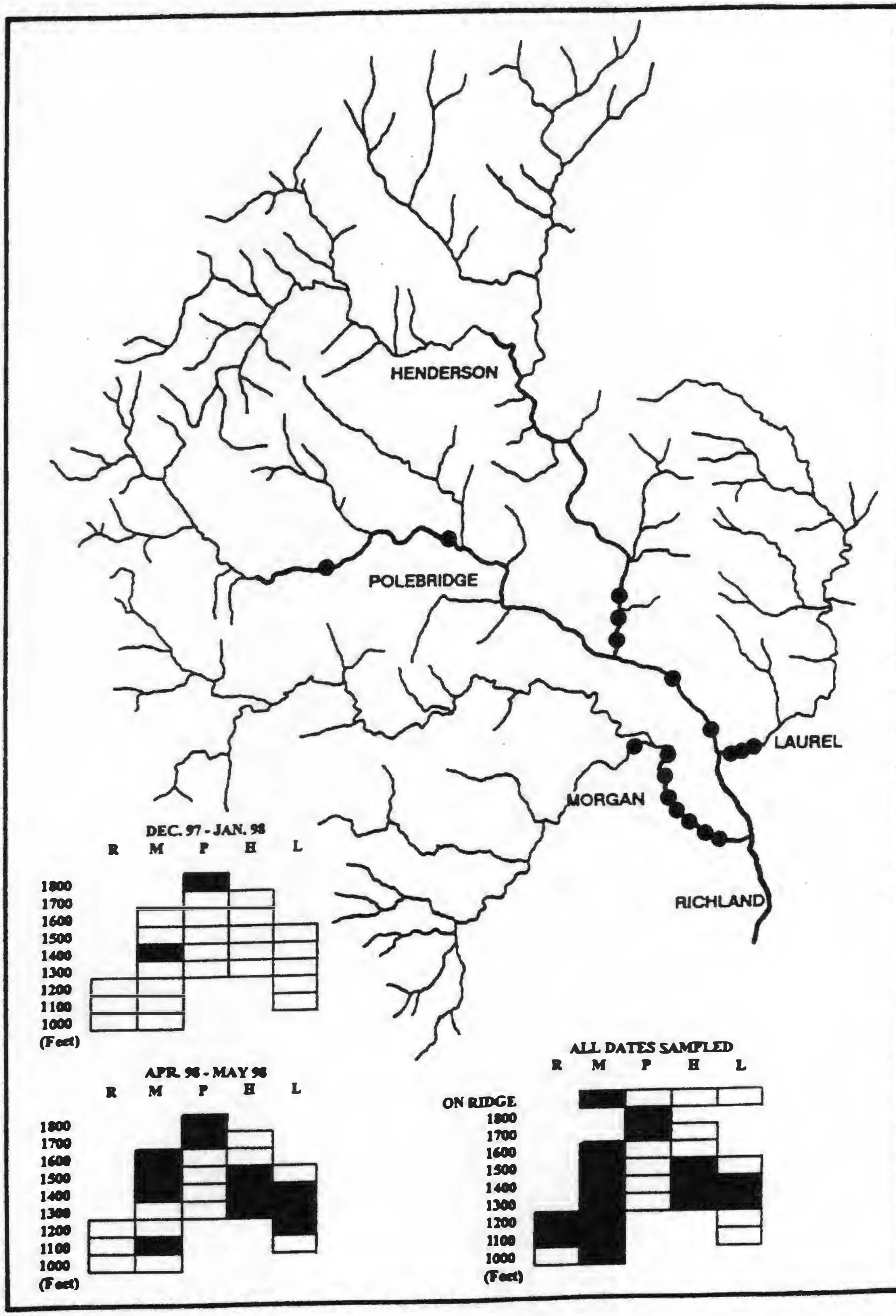

FIGURE 17. Distribution of *Acentrella* sp. (Ephemeroptera, Family Baetidae).

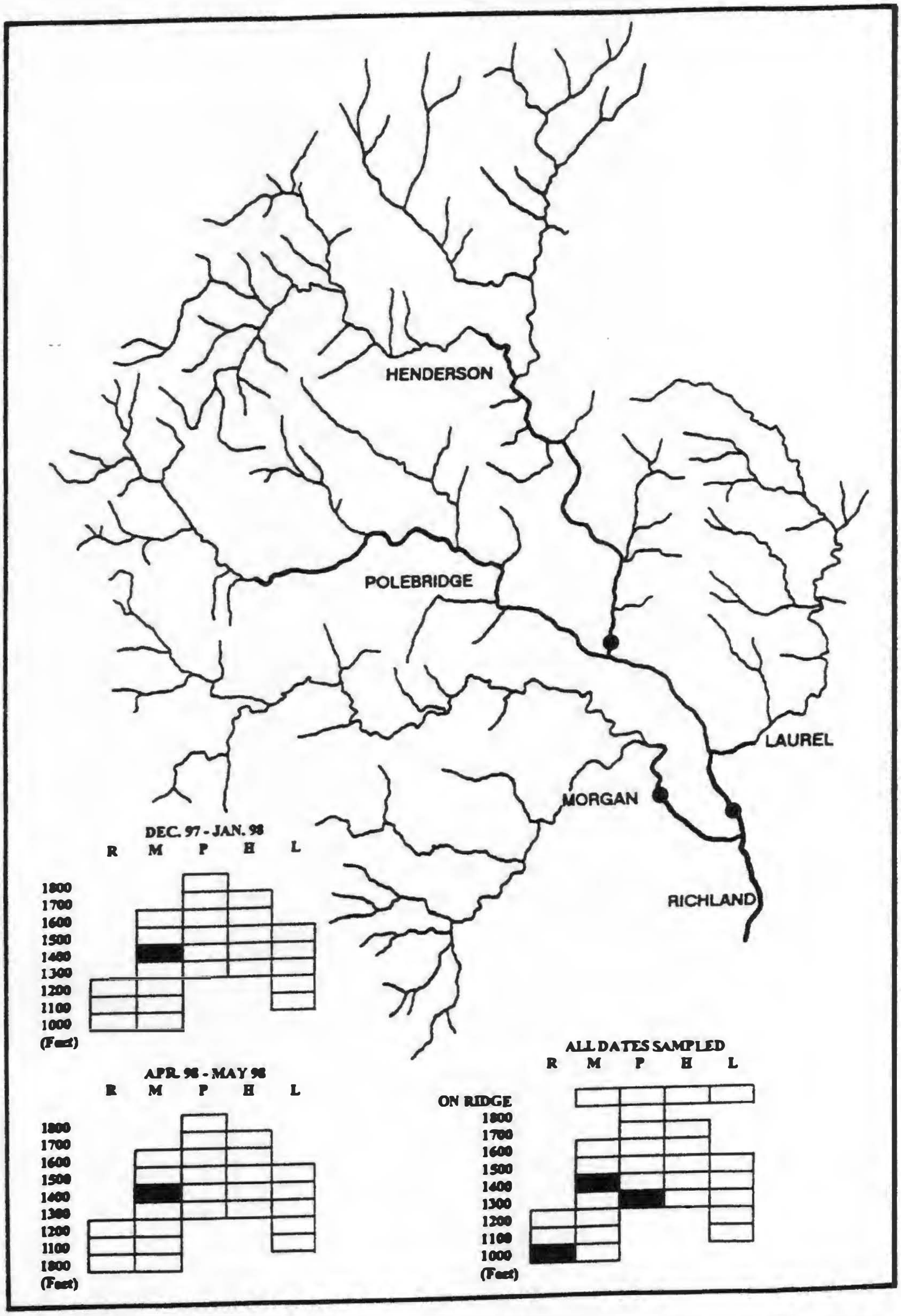

FIGURE 18. Distribution of *Baetis pluto*. (Ephemeroptera, Family Baetidae).

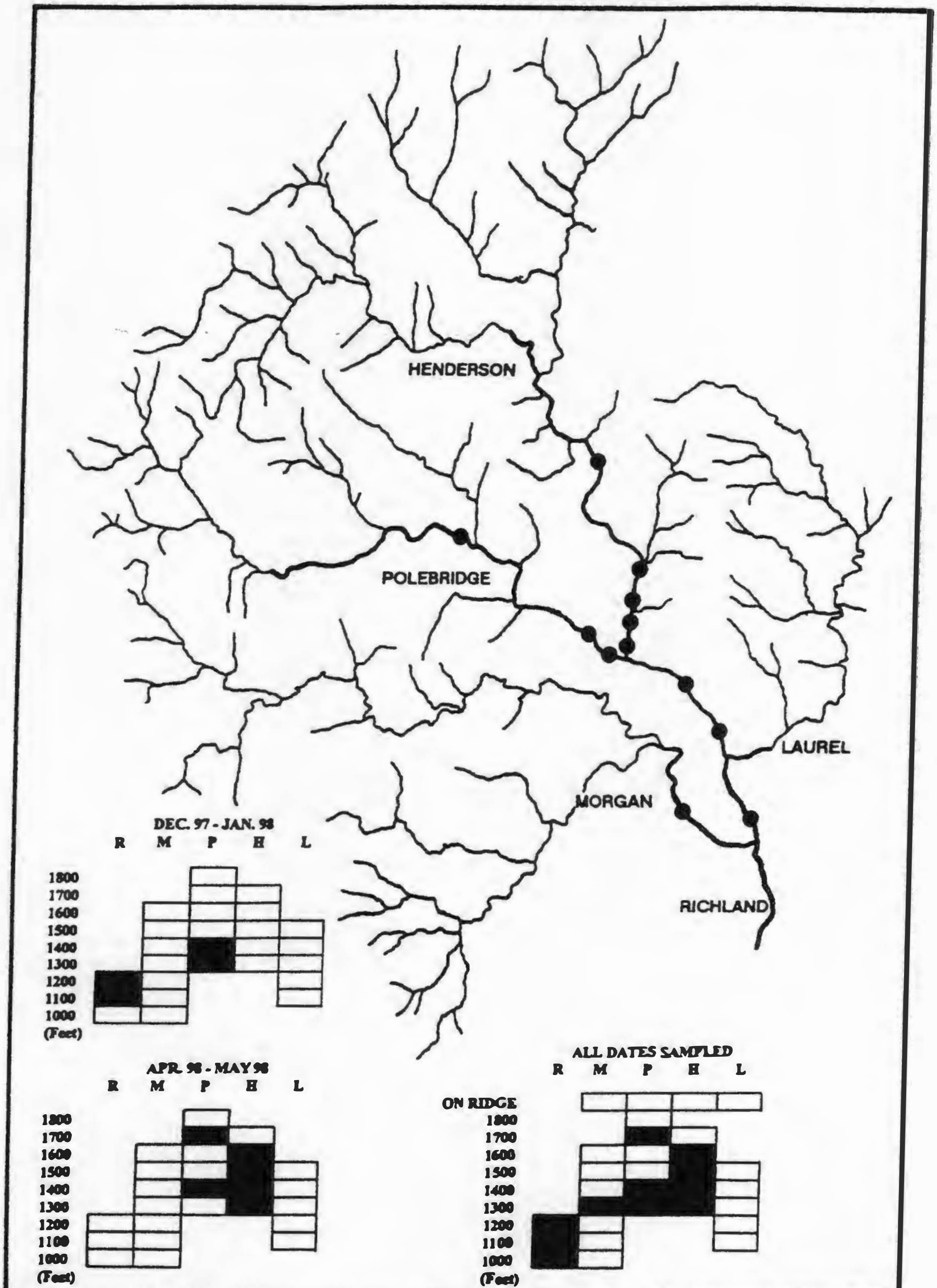

FIGURE 19. Distributions of *Epeorus dispar* (Ephemeroptera, Family Heptageniidae).

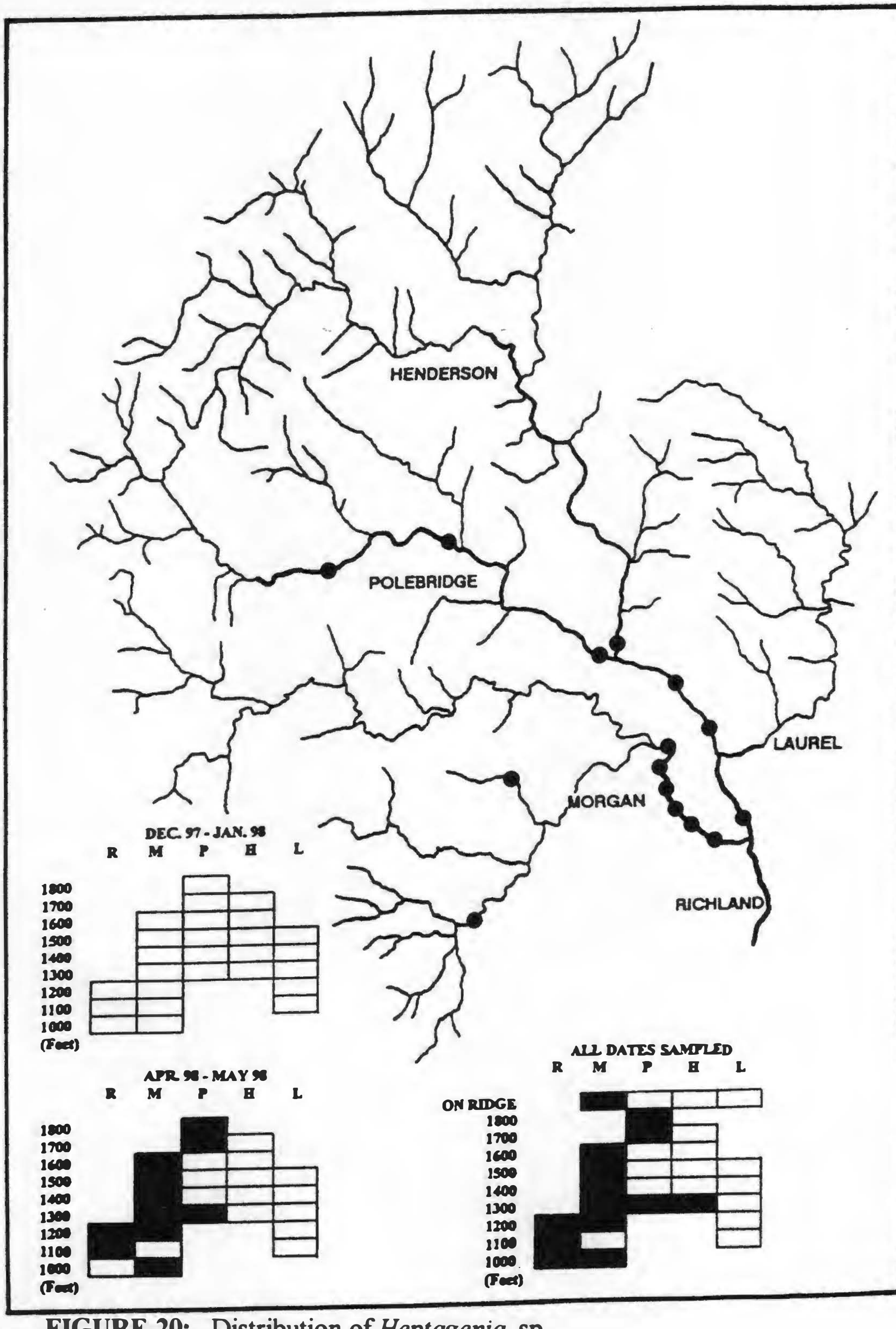

FIGURE 20: Distribution of *Heptagenia* sp.
(Ephemeroptera, Family Heptageniidae)

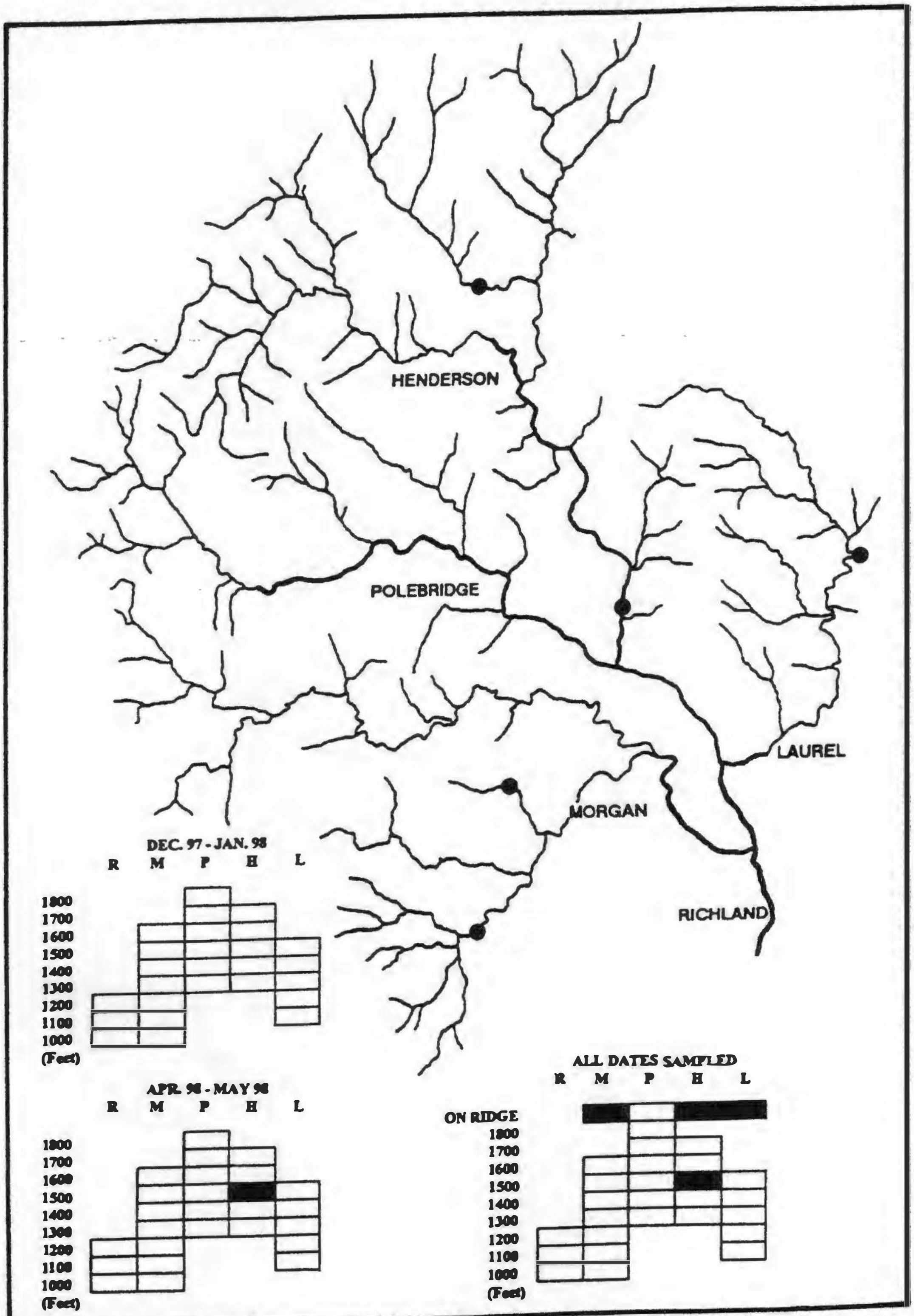

FIGURE 21. Distribution of *Stenacron pallidum* (Ephemeroptera, Family Heptageniidae).

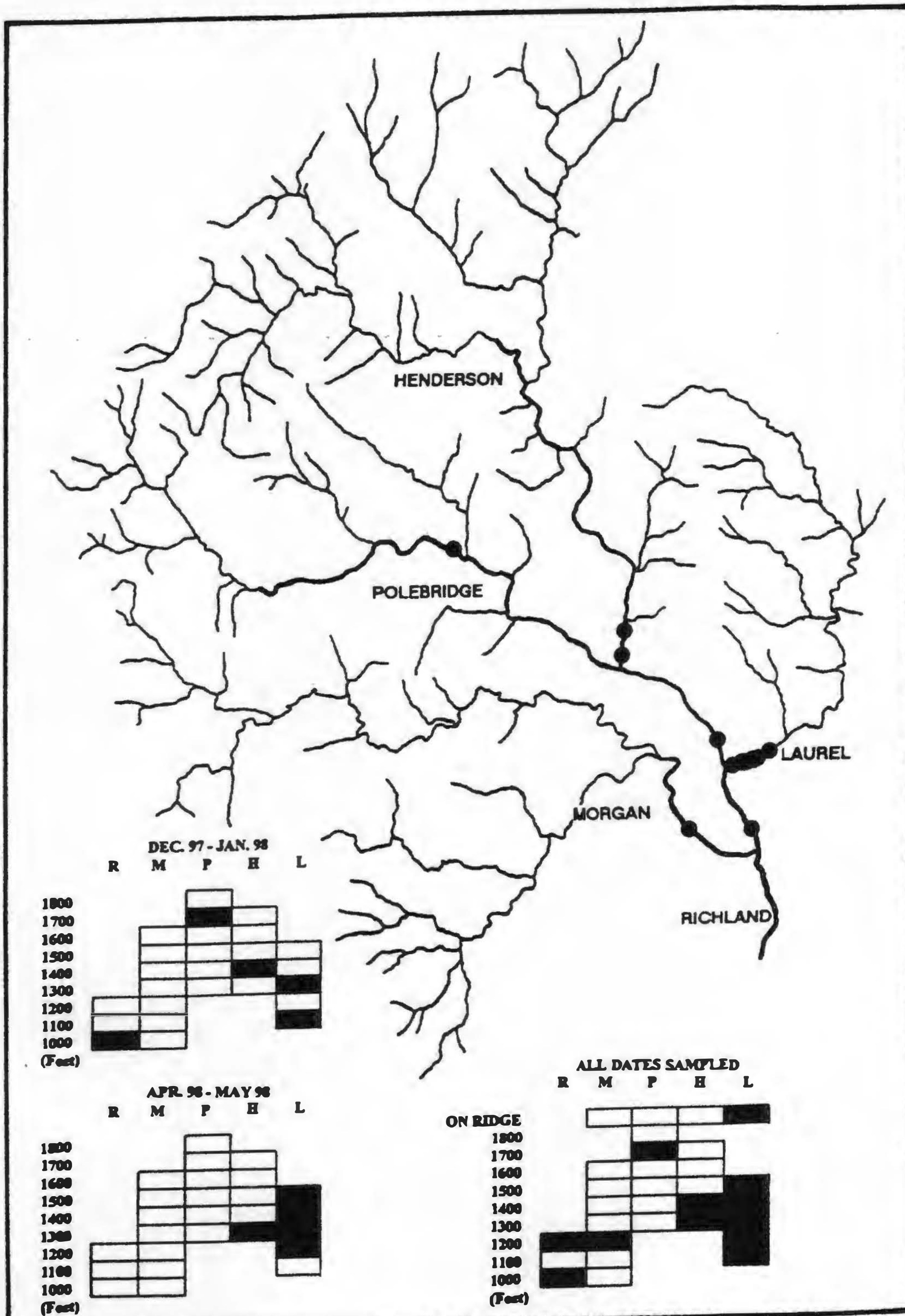

FIGURE 22. Distribution of *Stenonema sinclairi* (Ephemeroptera, Family Heptageniidae).

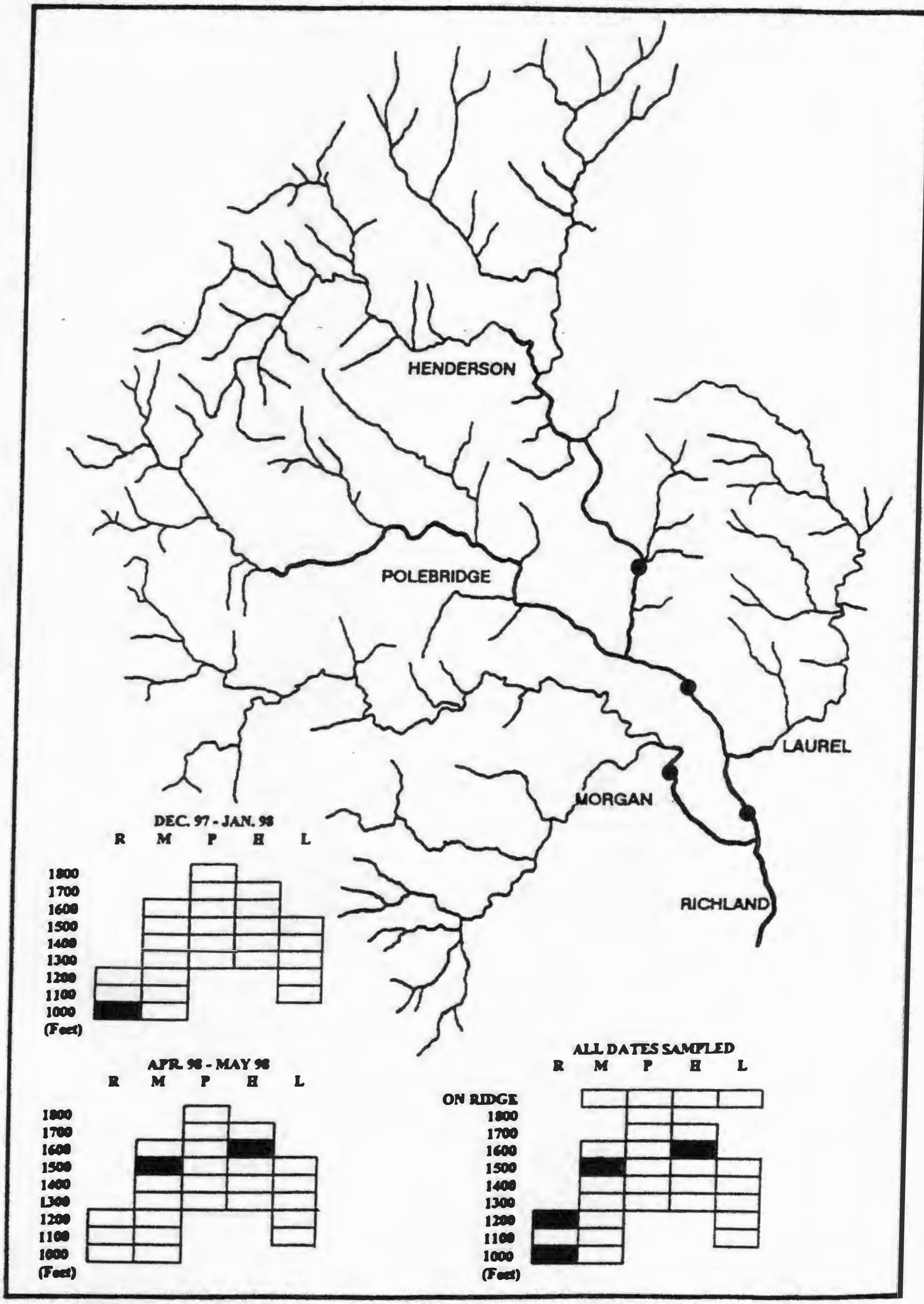

FIGURE 23. Distribution of *Isonychia* sp. (Ephemeroptera, Family Isonychiidae).

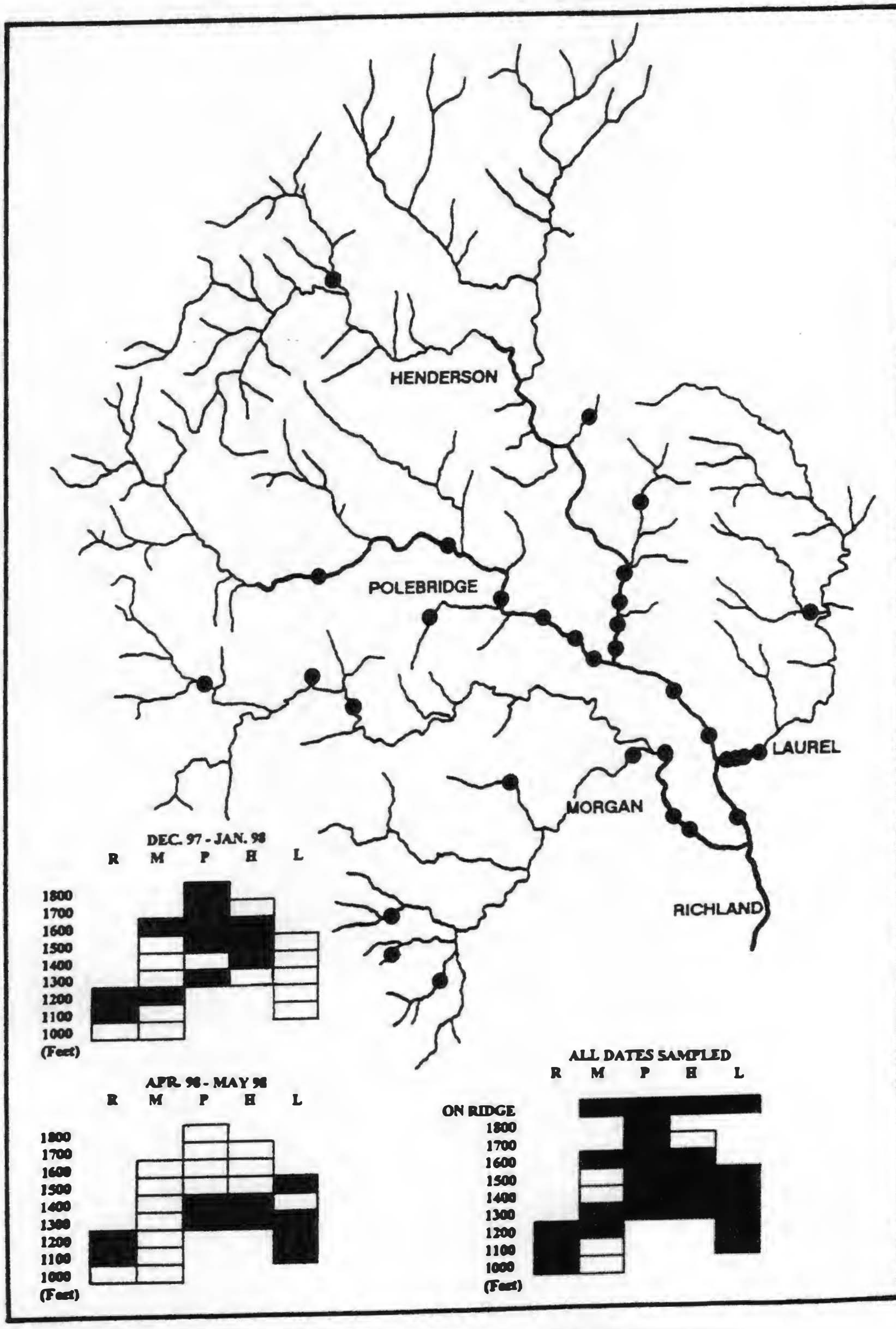

FIGURE 24. Distribution of *Ameletus lineatus* (Ephemeroptera, Family Ameletidae).

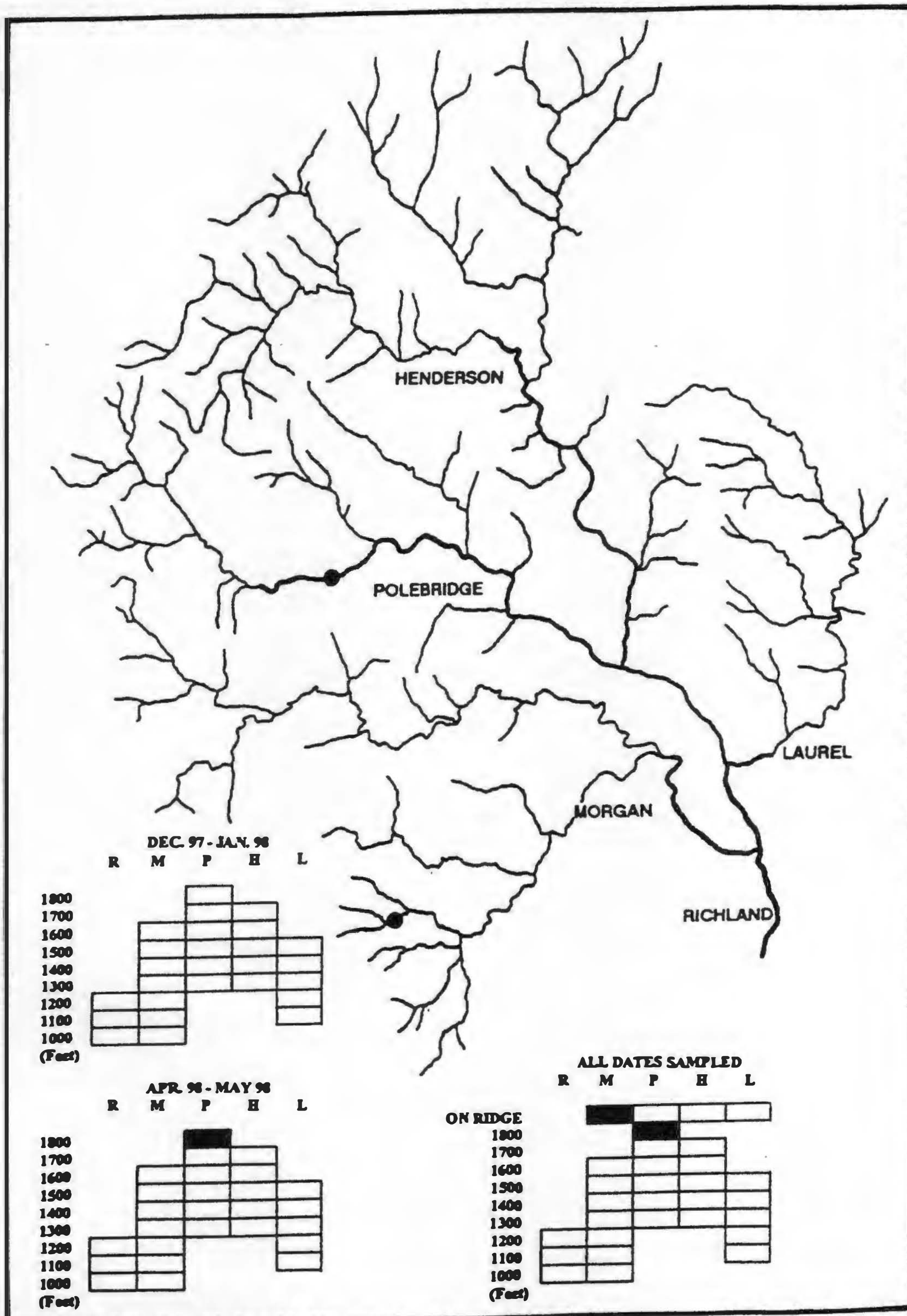

FIGURE 25. Distribution of *Paraleptophlebia* sp. (Ephemeroptera, Family Leptophlebiidae).

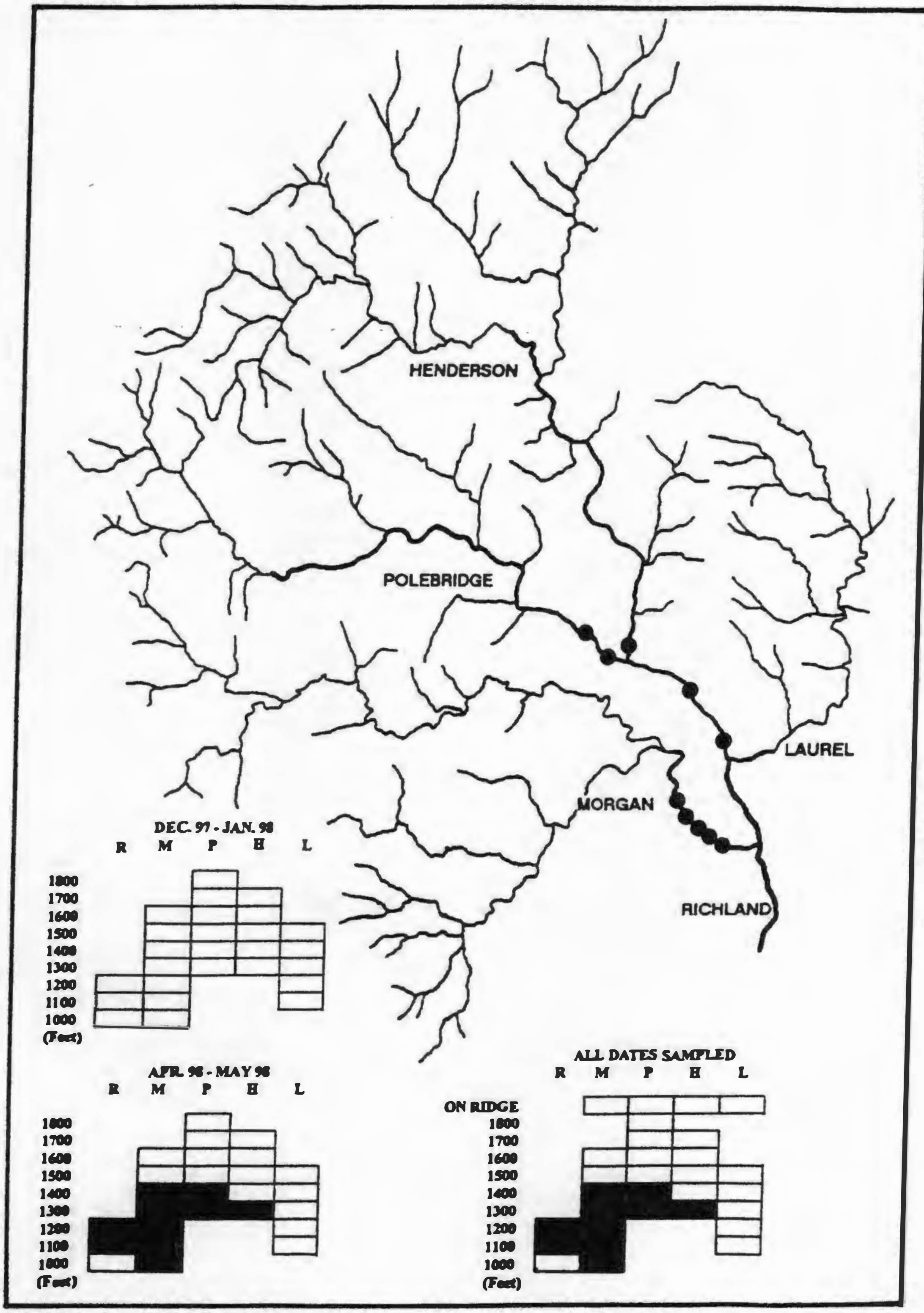

FIGURE 26. Distribution of *Drunella cornuta* (Ephemeroptera, Family Ephemerellidae).

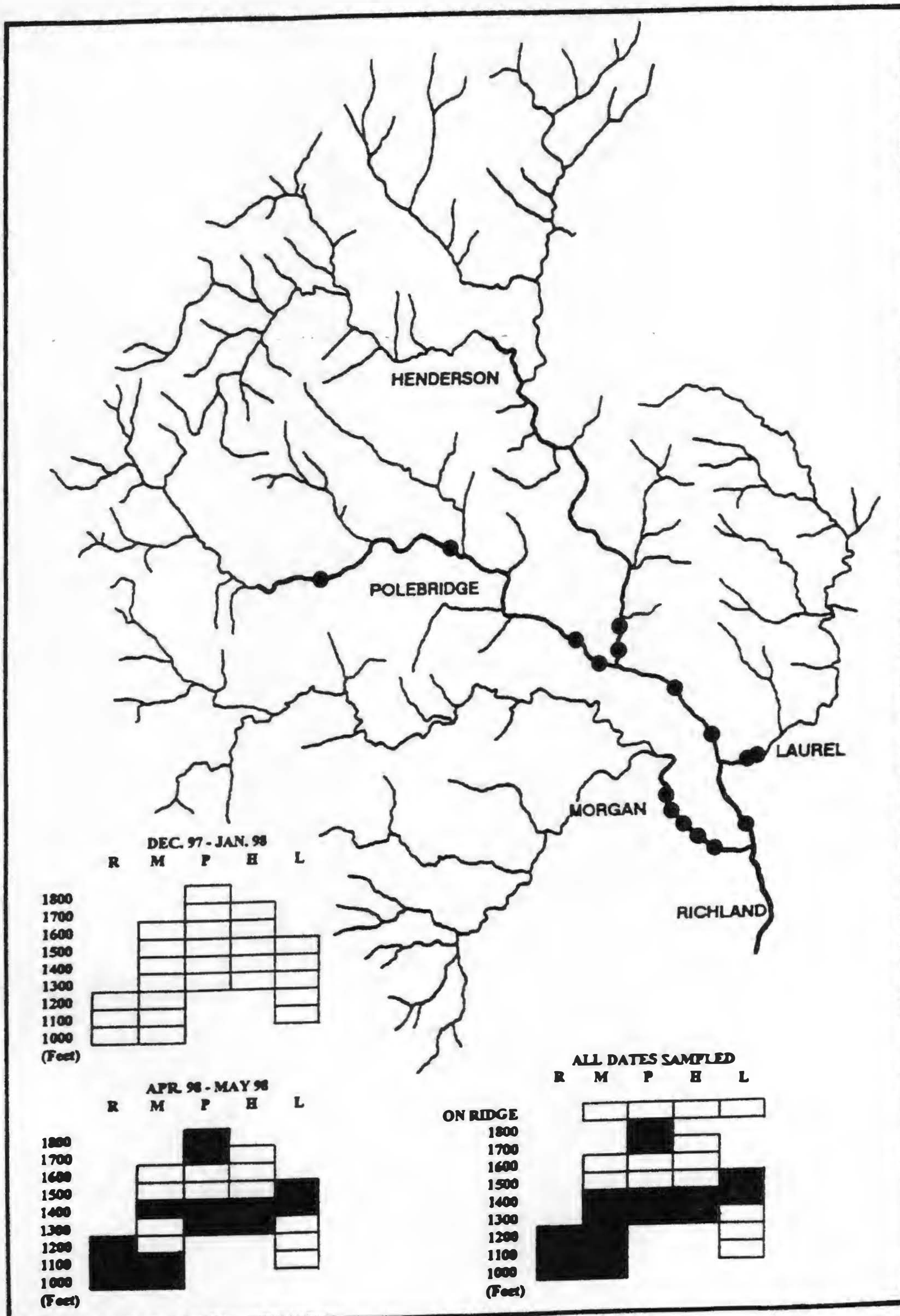

FIGURE 27. Distribution of *Ephemerella dorothea* (Ephemeroptera, Family Ephemerellidae).

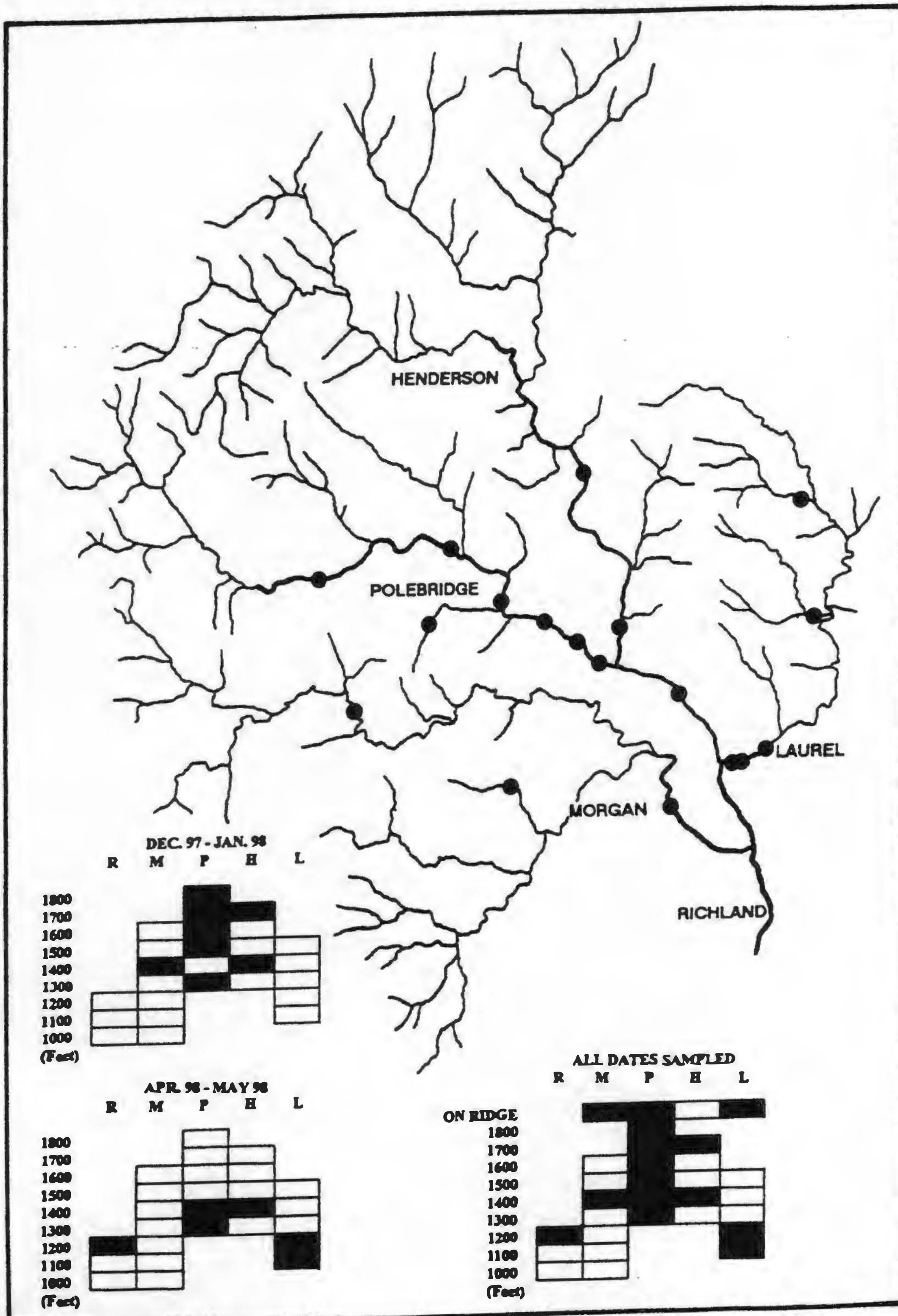

FIGURE 28. Distribution of *Eurylophella funeralis* (Ephemeroptera, Family Ephemerellidae).

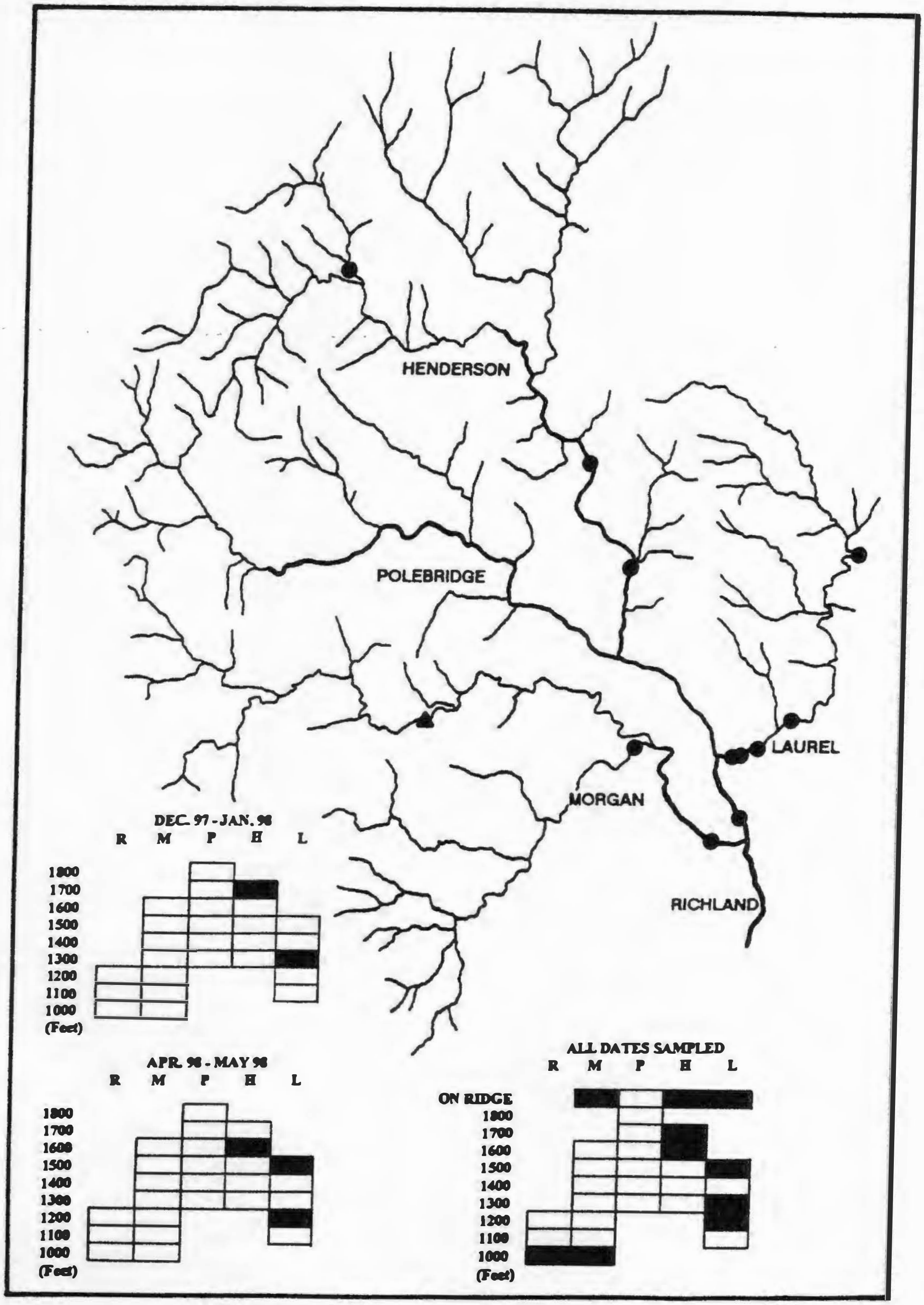

FIGURE 29. Distribution of *Boyeria grafiana* (●) and *Boyeria vinosa* (▲) (Odonata, Family Aeshnidae).

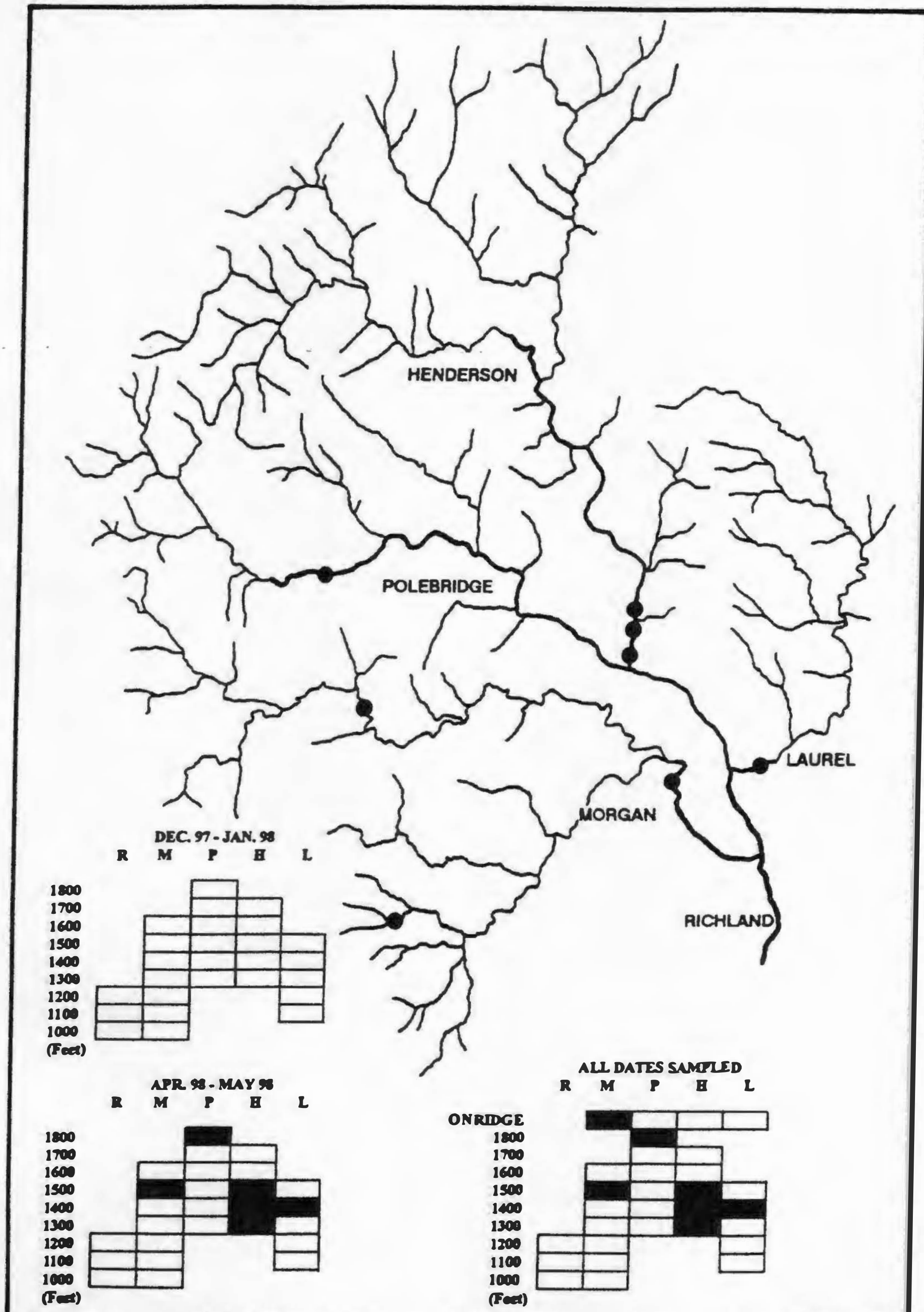

FIGURE 30. Distribution of *Amphinemura nigritta delosa* (Plecoptera, Family Nemouridae).

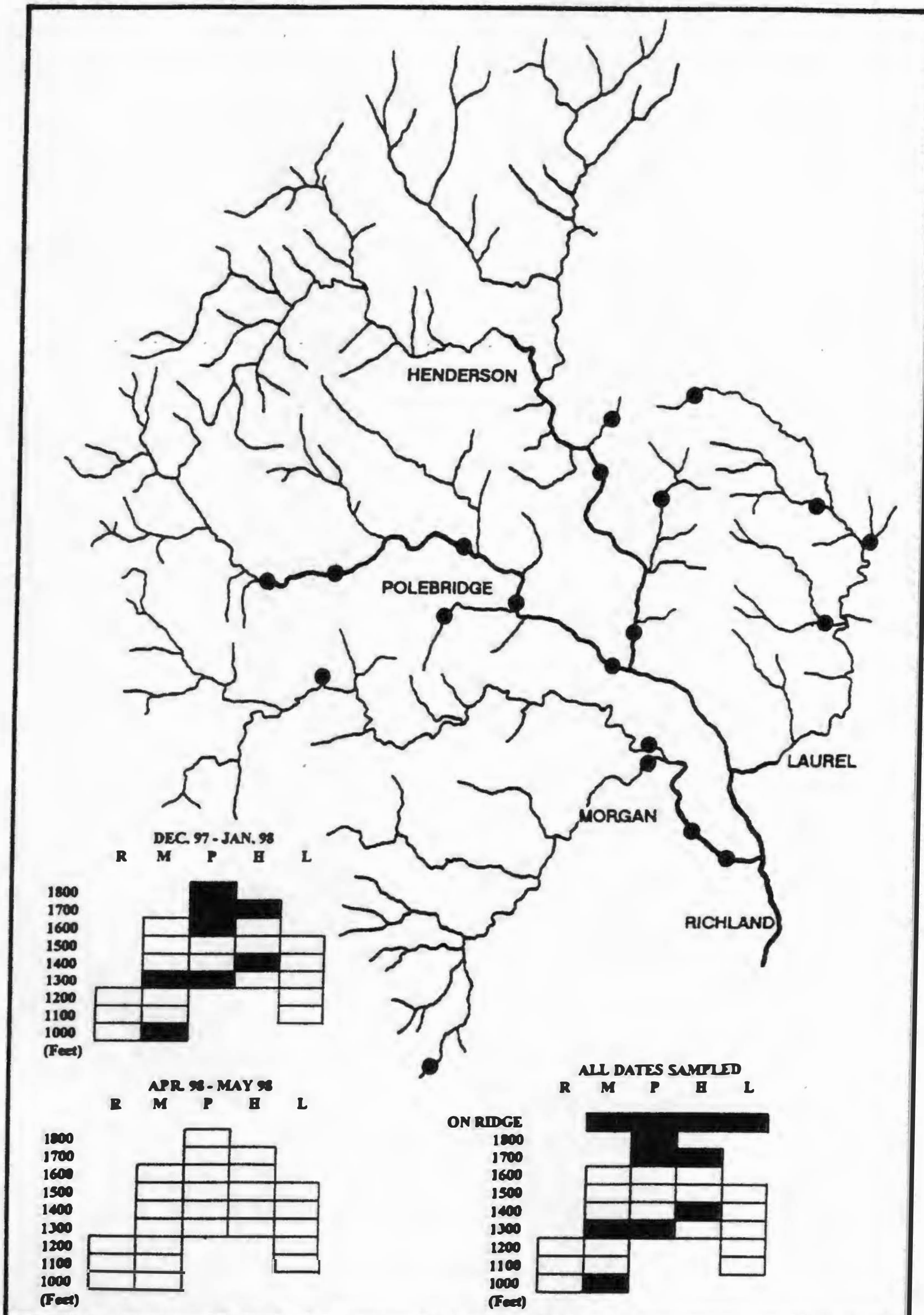

FIGURE 31. Distribution of *Oemopteryx contorta* (Plecoptera, Family Taeniopterygidae).

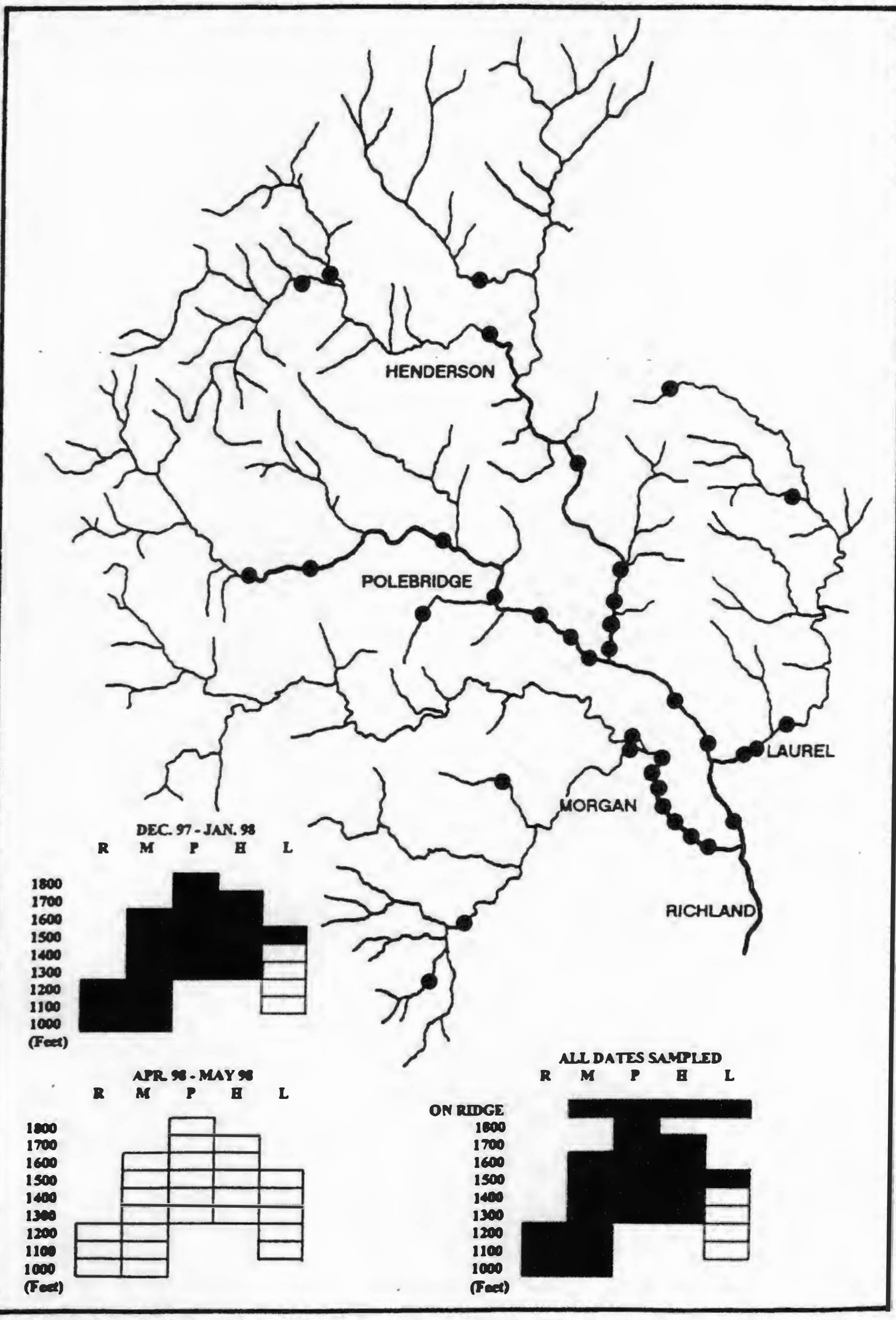

FIGURE 32. Distribution of *Taeniopteryx* sp.
(Plecoptera, Family Taeniopterygidae)

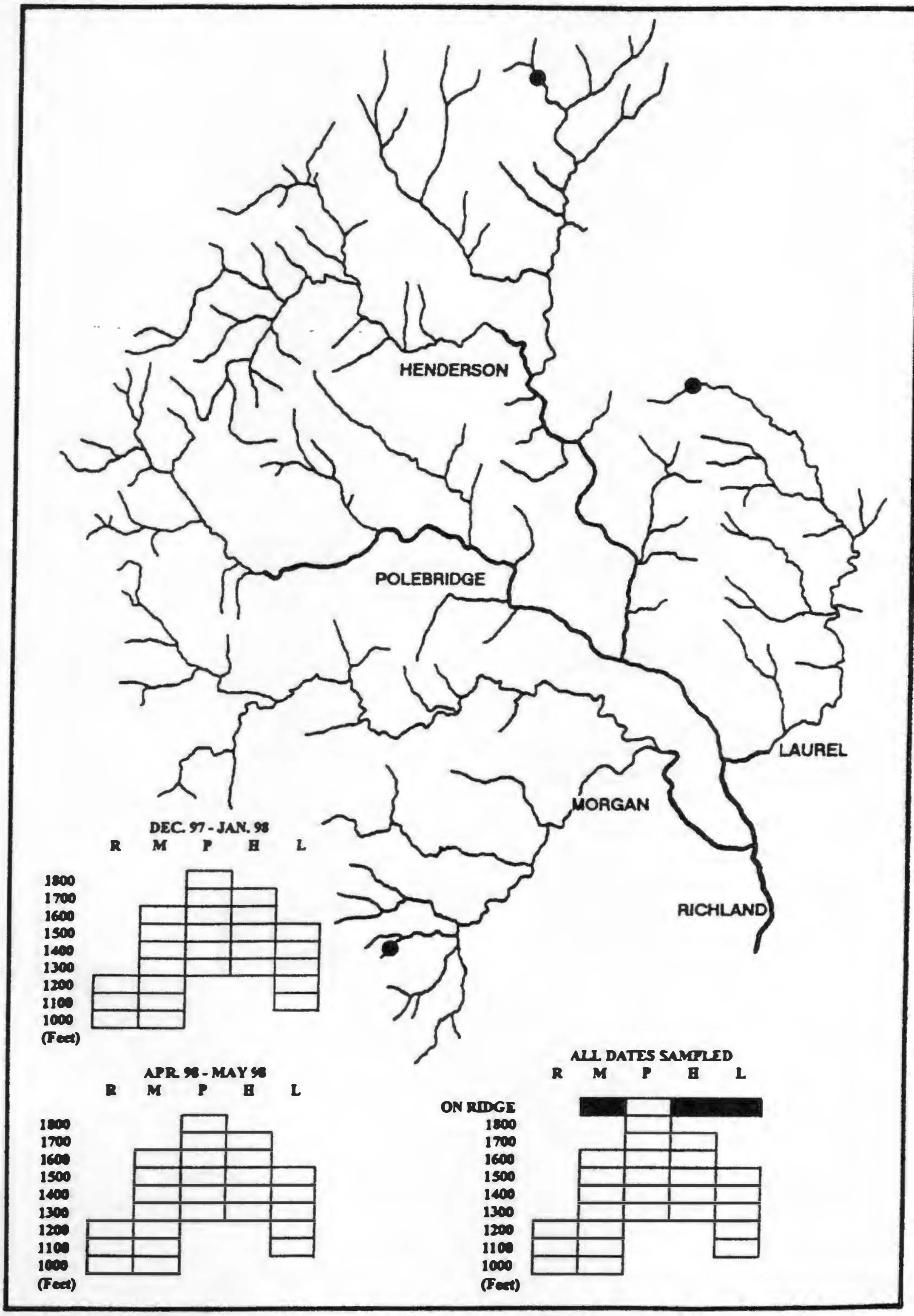

FIGURE 33. Distribution of *Allocapnia* sp. (Plecoptera, Family Capniidae).

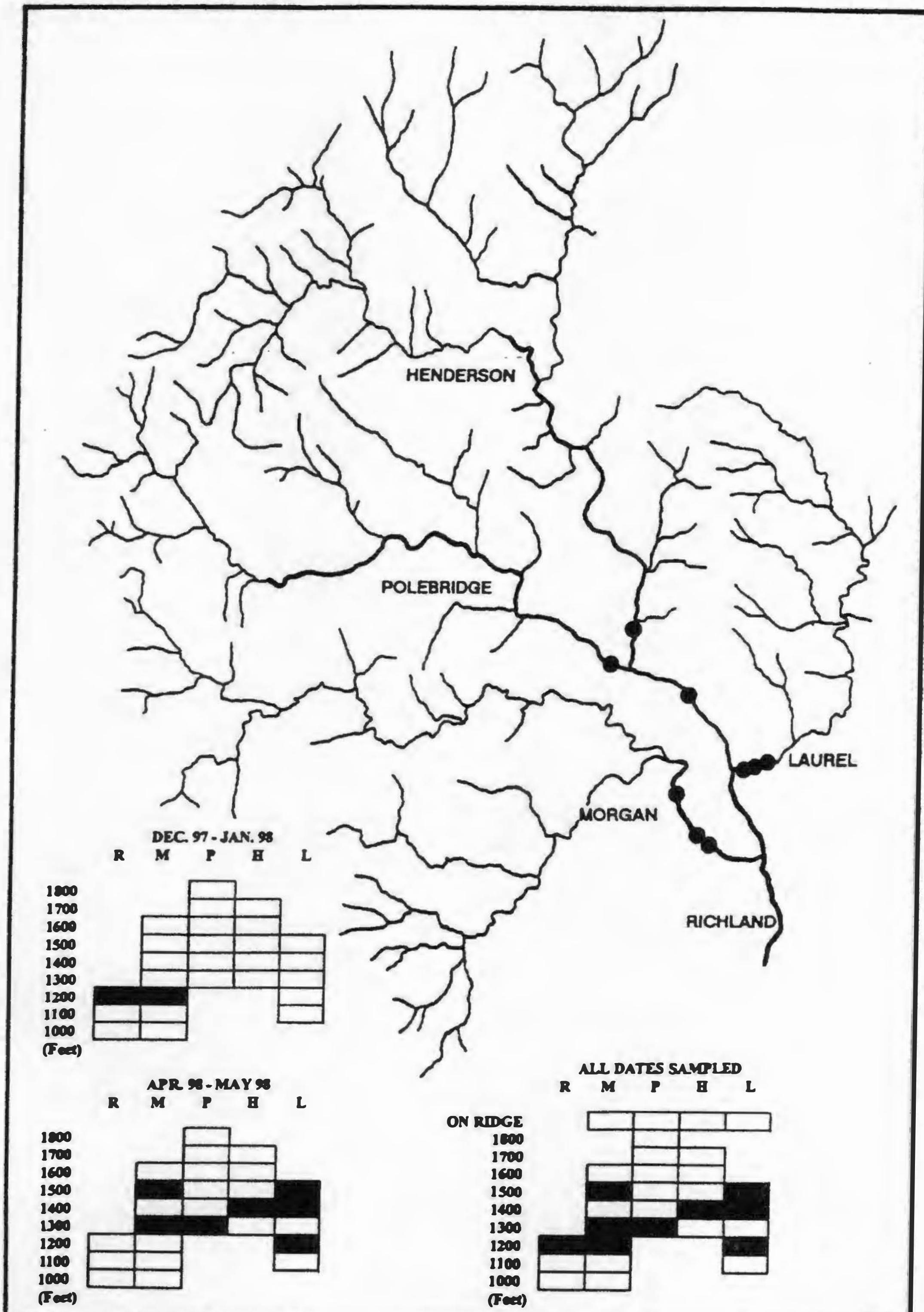

FIGURE 34: Distribution of *Leuctra* sp. (Plecoptera, Family Leuctridae).

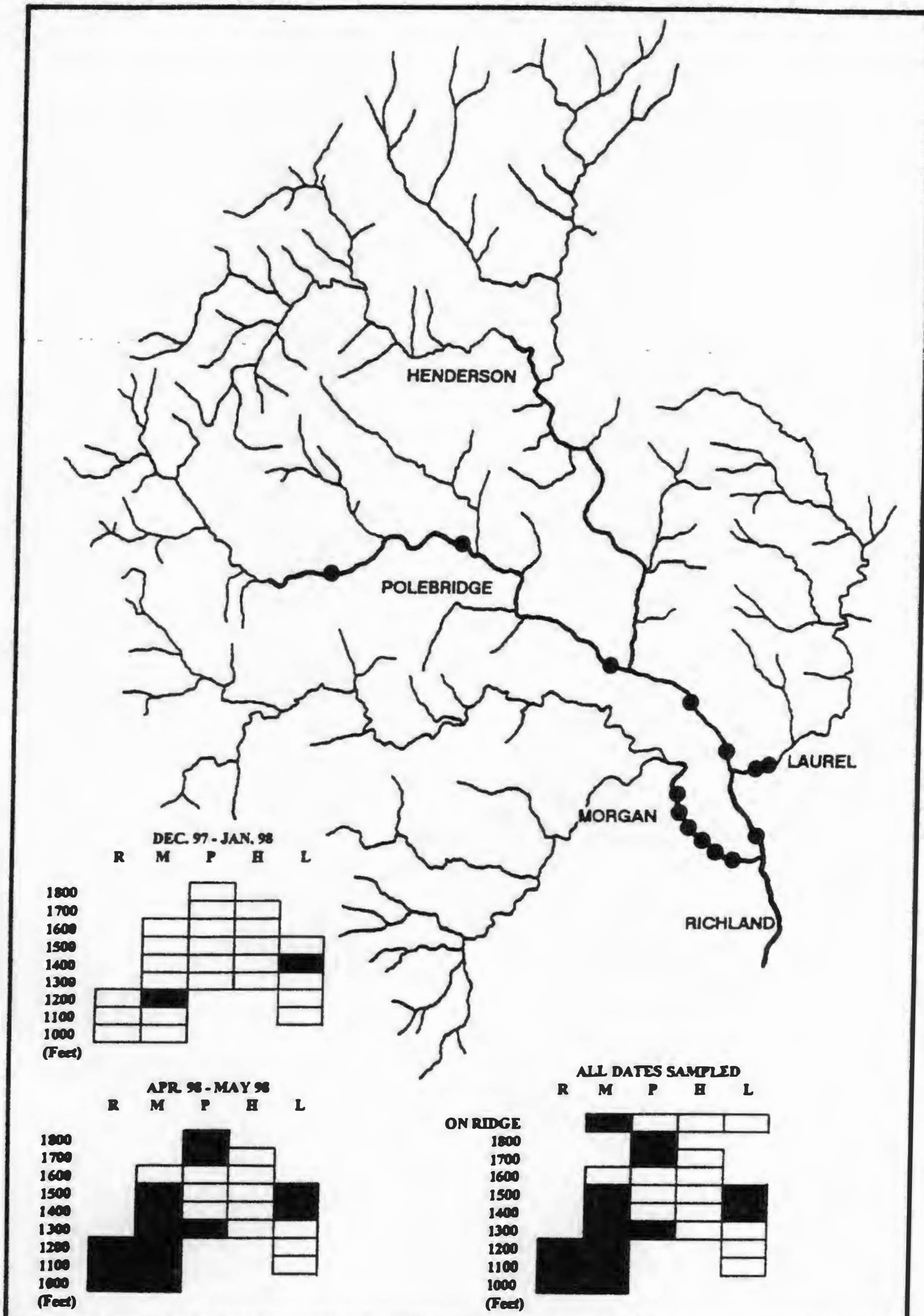

FIGURE 35. Distribution of *Isoperla holochlora* (Plecoptera, Family Perlodidae).

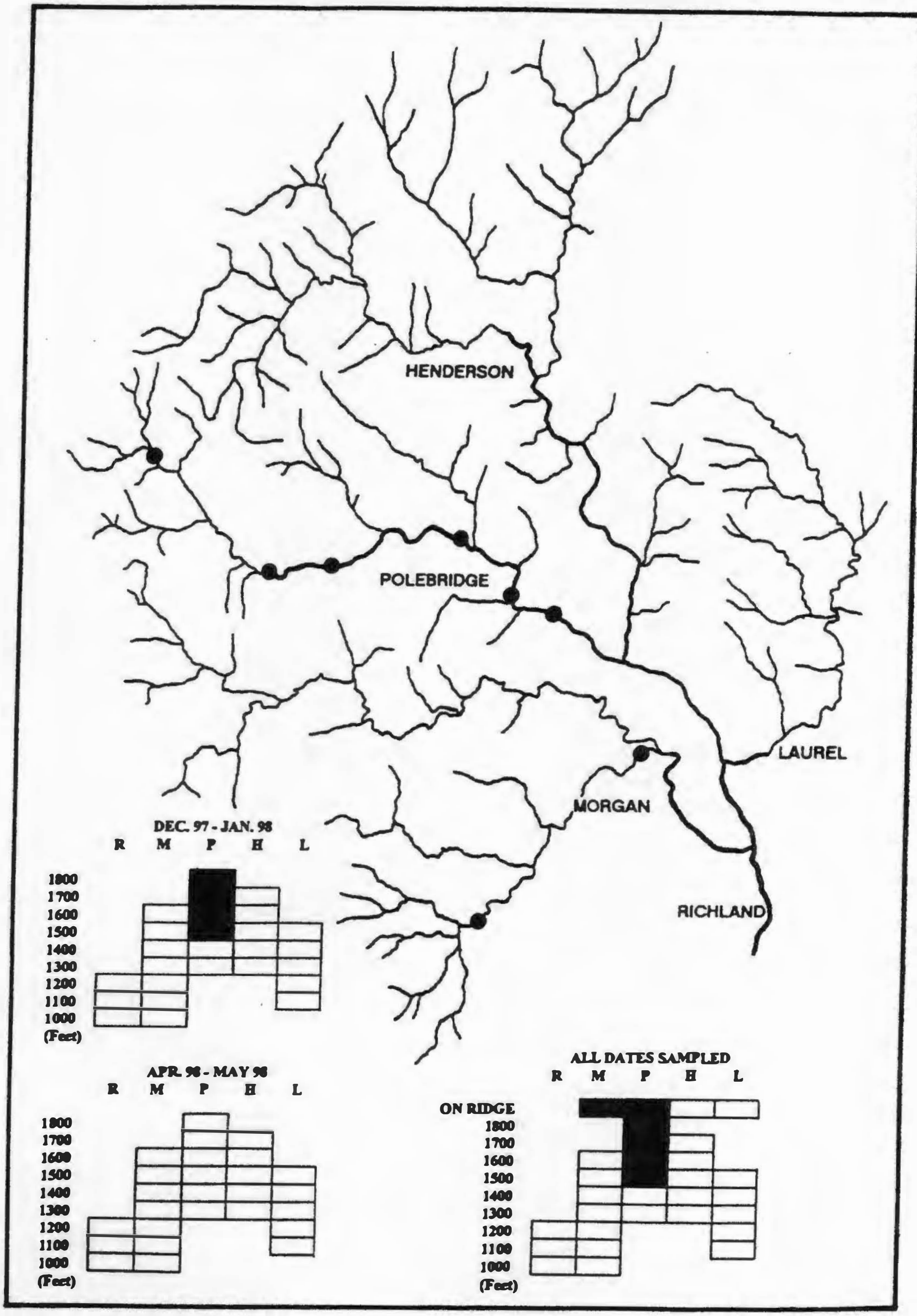

FIGURE 36. Distribution of *Isoperla similis* (Plecoptera, Family Perlodidae).

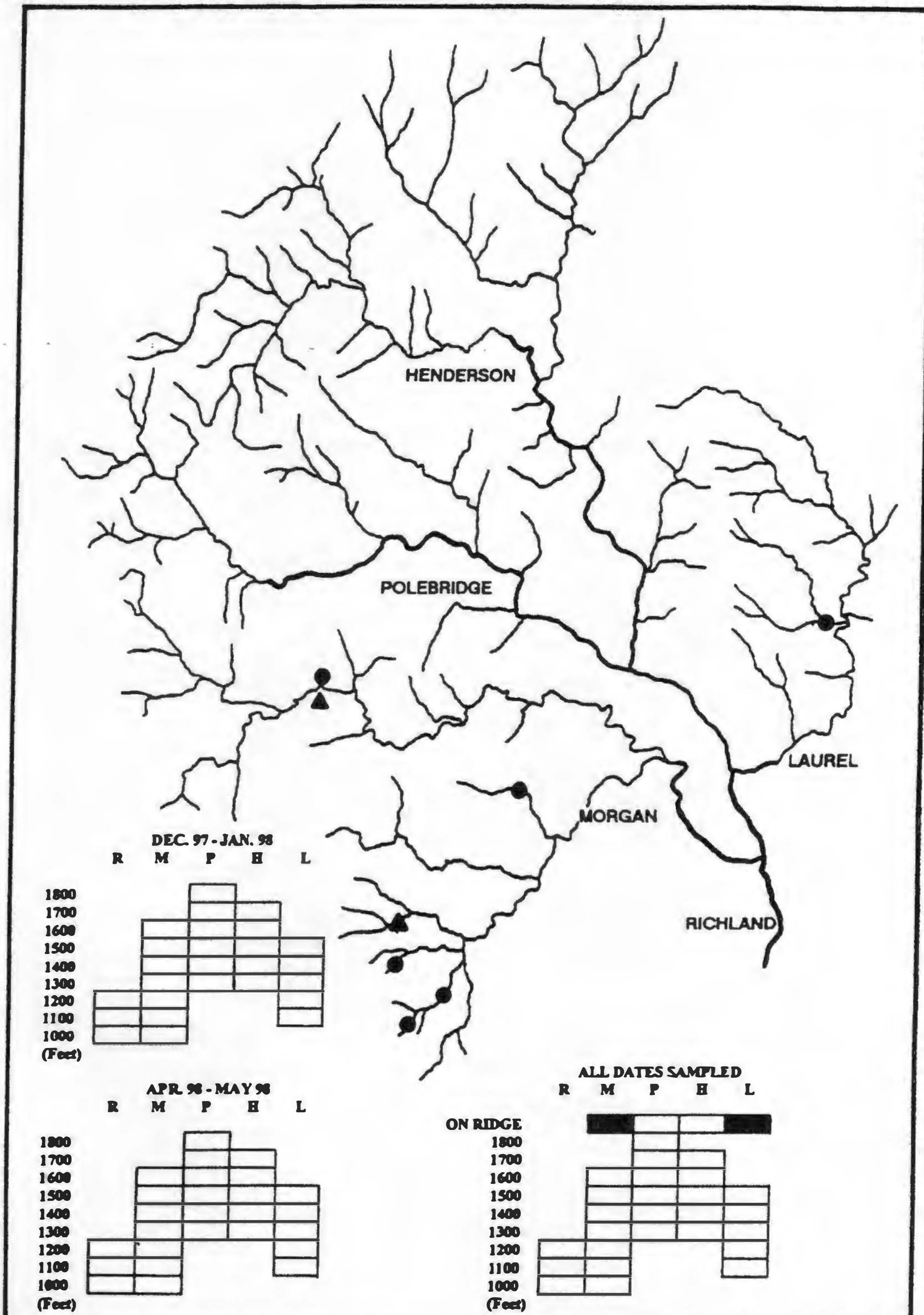

FIGURE 37. Distribution of *Clioperla clio* (●) and *Diploperla duplicata* (▲) (Plecoptera, Family Perlodidae).

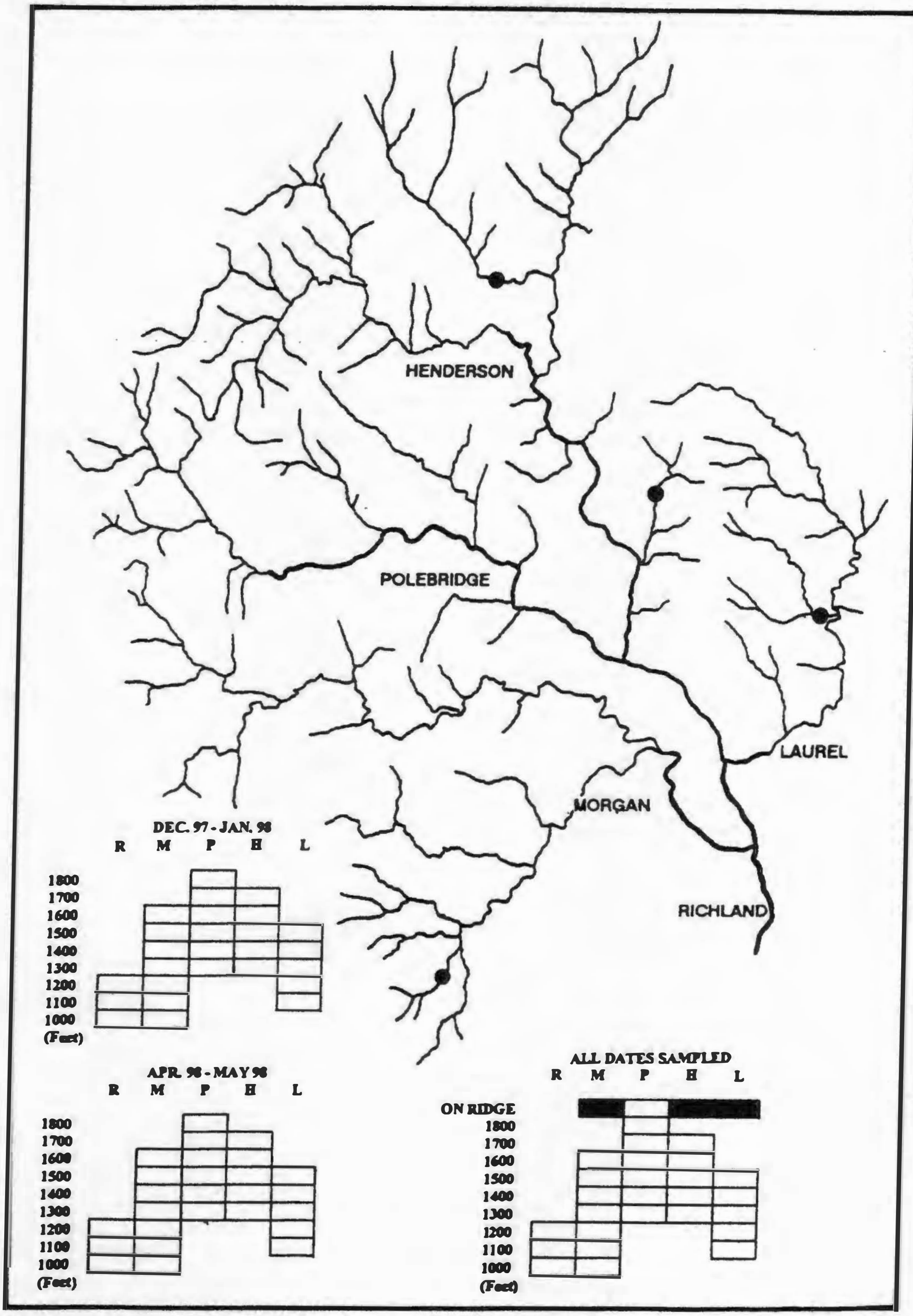

FIGURE 38. Distribution of *Cultus decisus* (Plecoptera, Family Perlodidae)

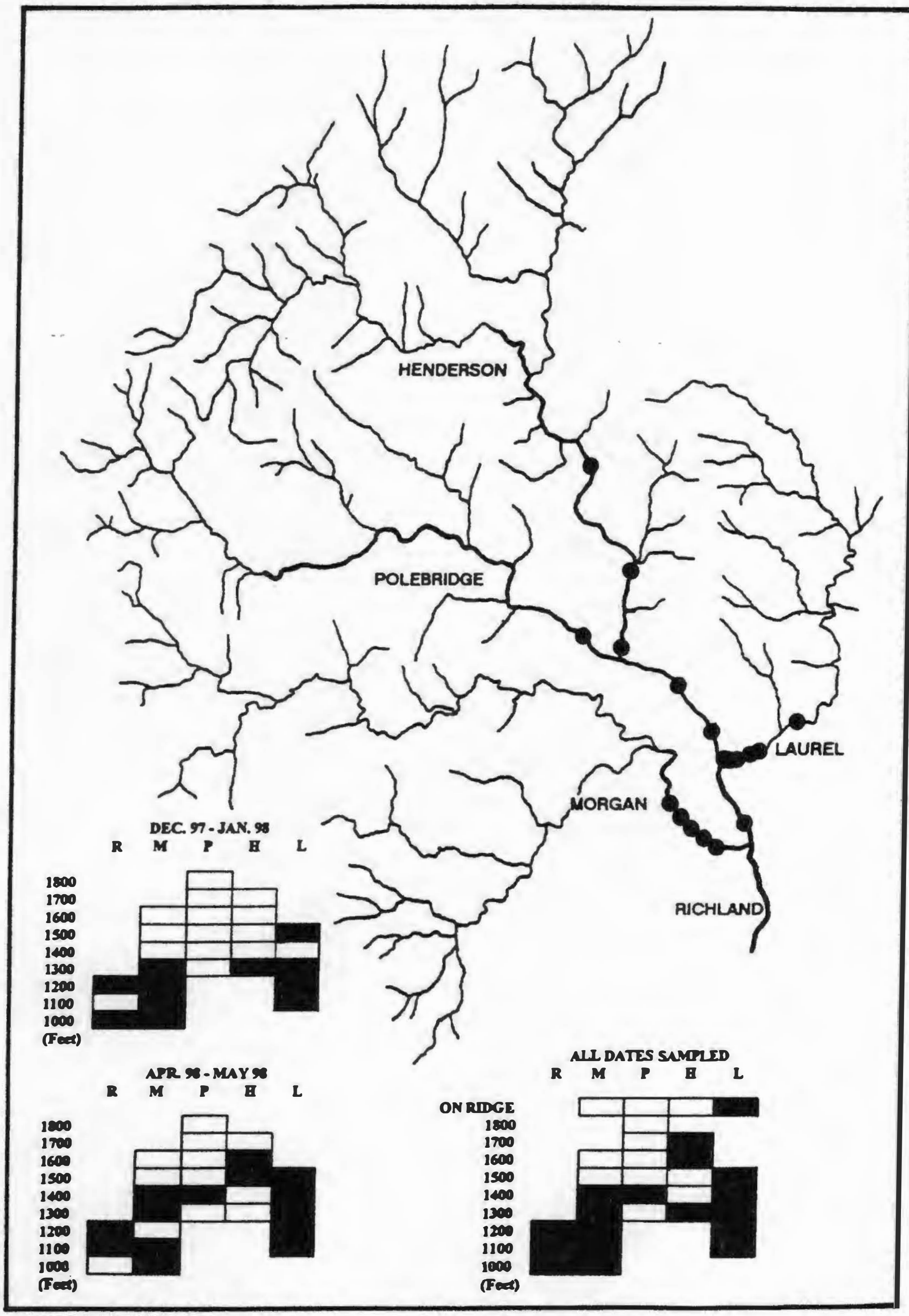

FIGURE 39. Distribution of *Acroneuria abnormis* (Plecoptera, Family Perlidae).

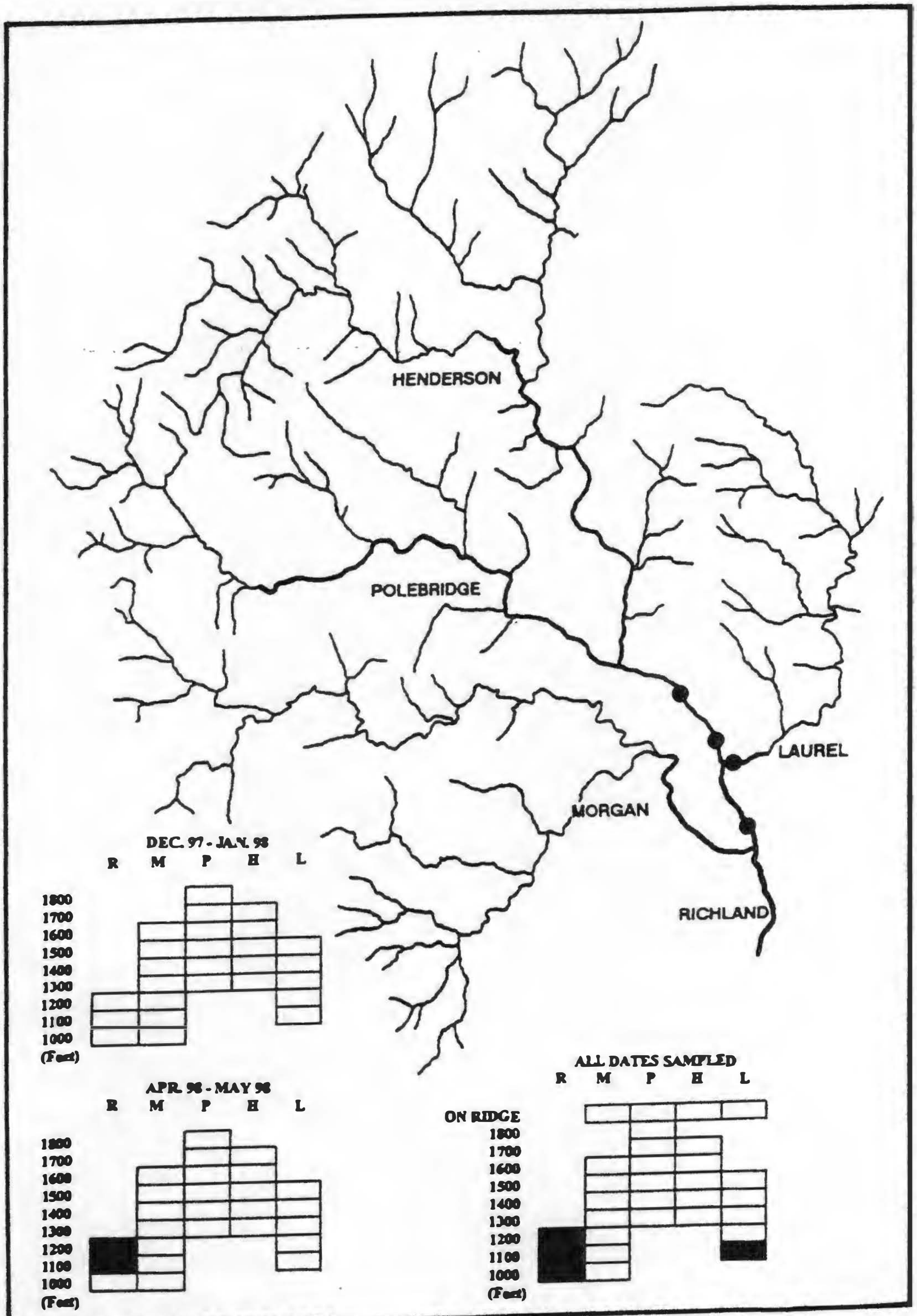

FIGURE 40. Distribution of *Acroneuria carolinensis* (Plecoptera, Family Perlidae).

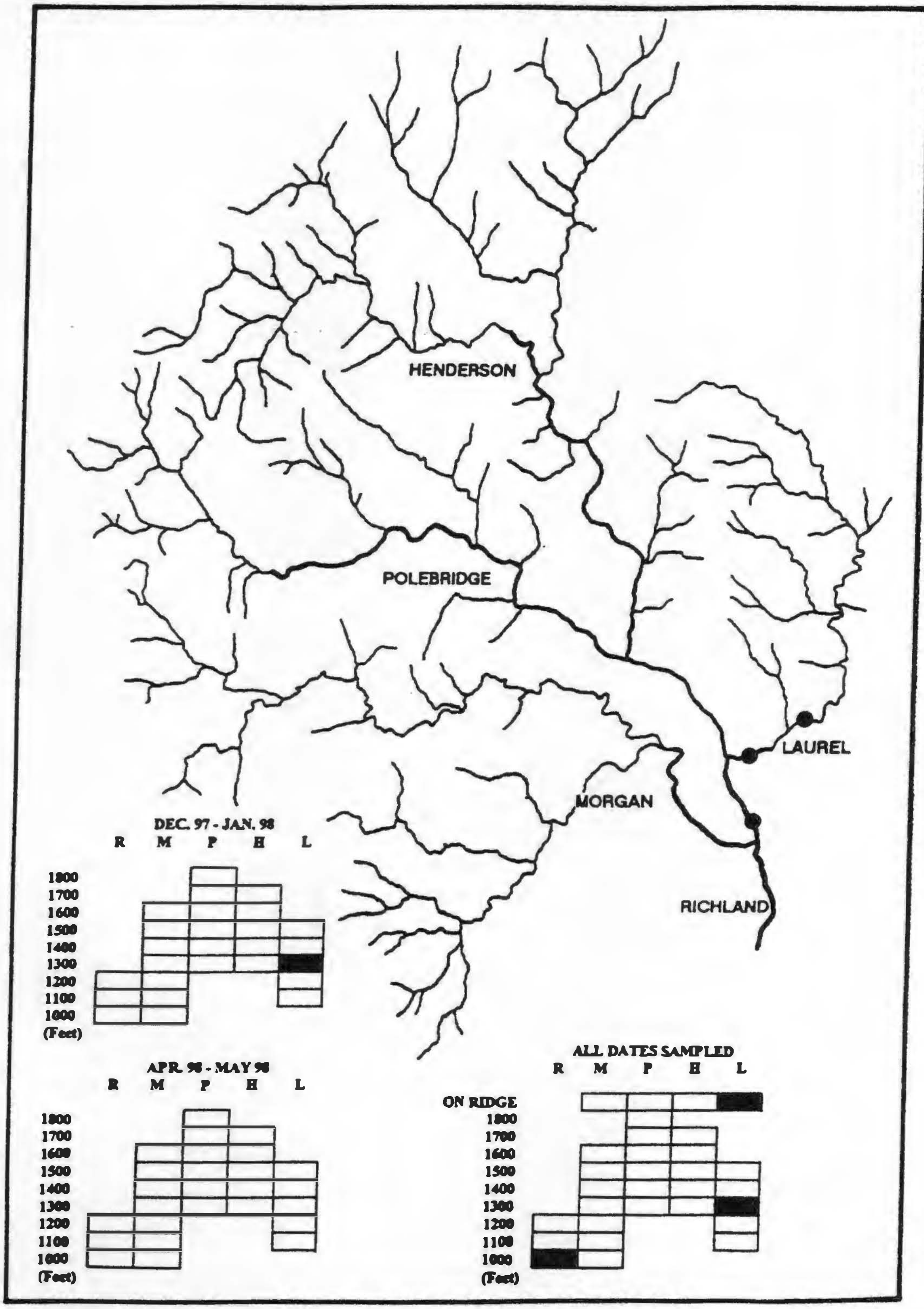

FIGURE 41. Distribution of *Acroneuria lycorias* (Plecoptera, Family Perlidae).

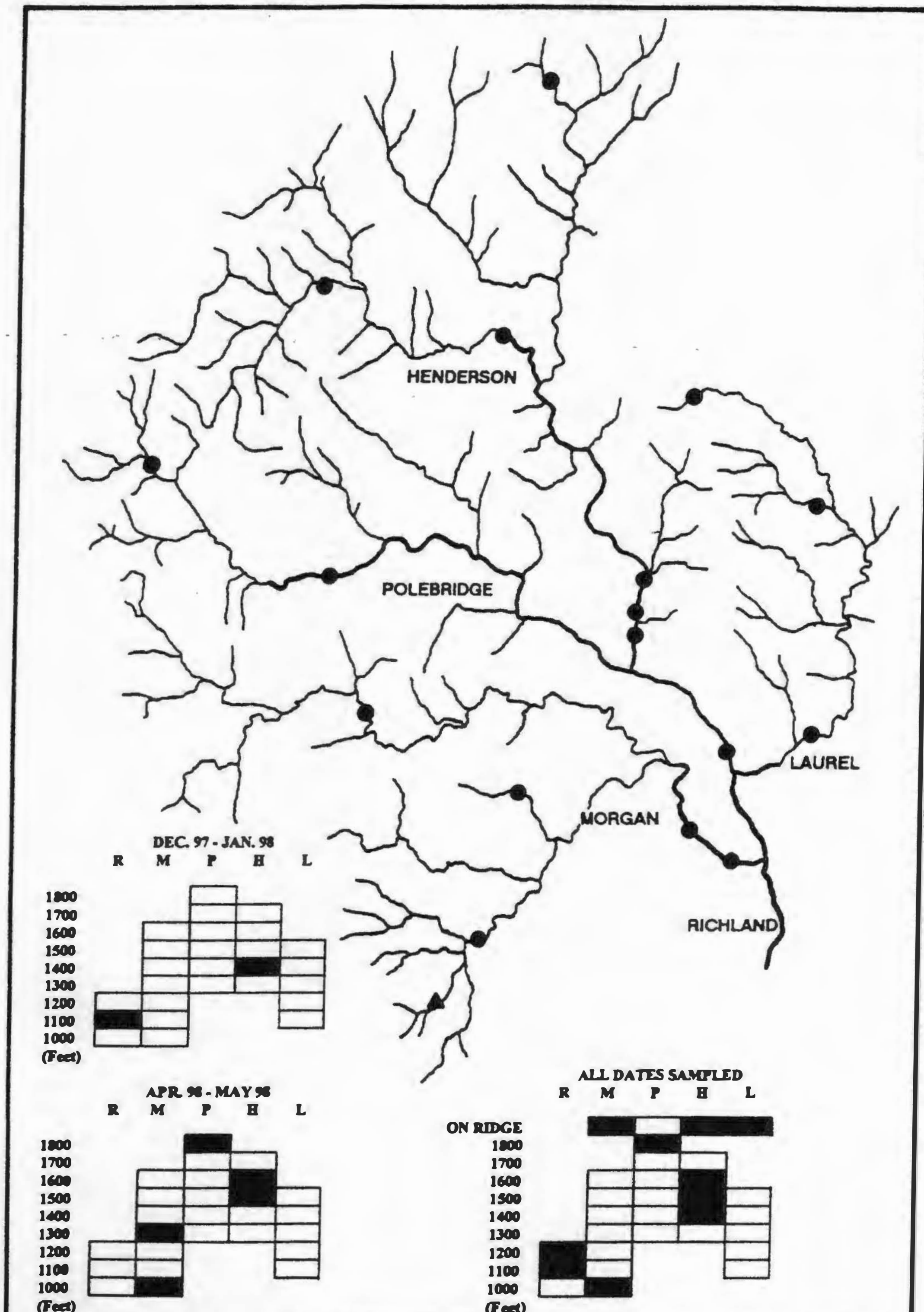

FIGURE 42. Distribution of *Nigronia serricornis* (●) and *Nigronia fasciatus* (▲) (Megaloptera, Family Corydalidae).

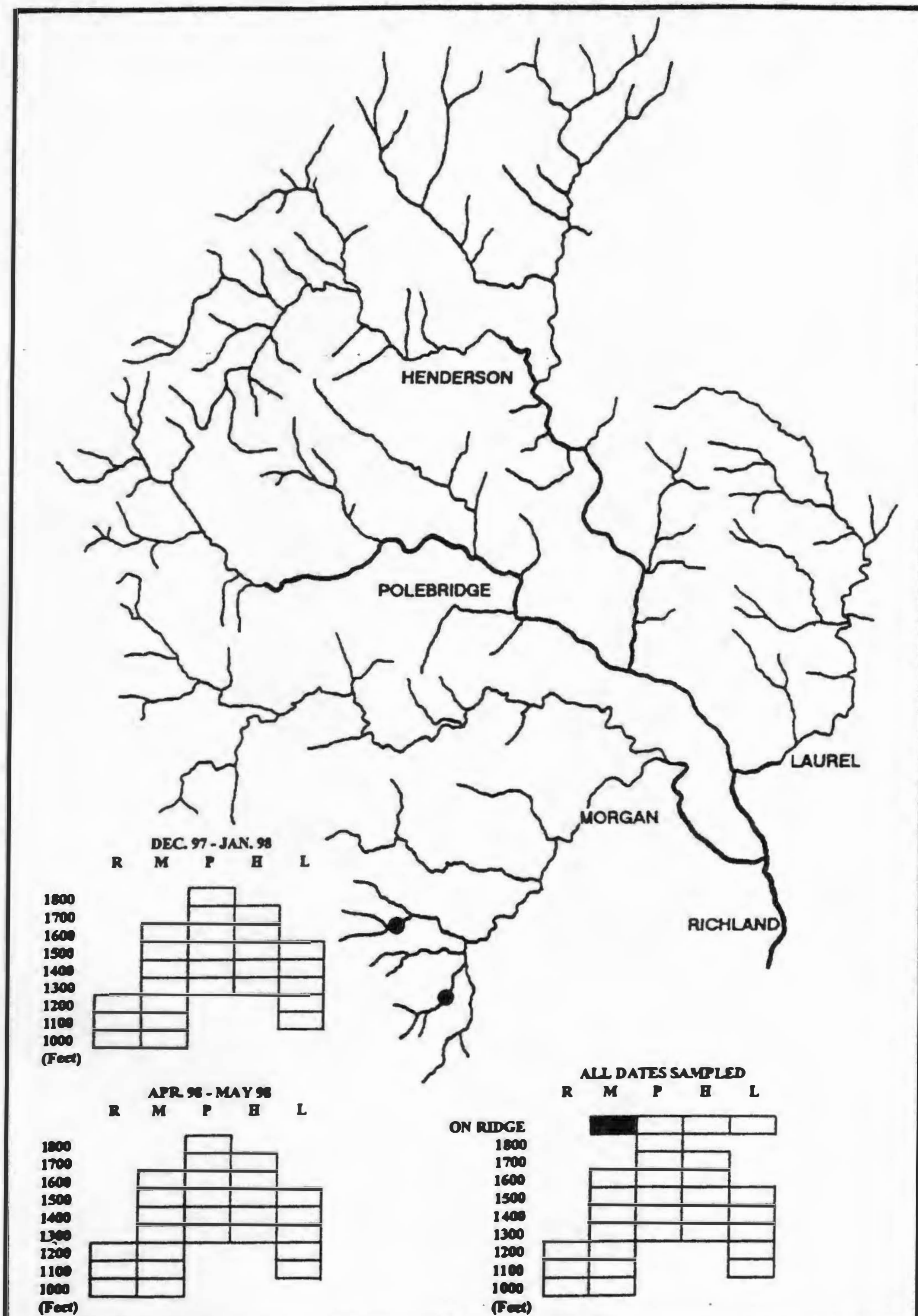

FIGURE 43. Distribution of *Sialis* sp. (Megaloptera, Family Sialidae).

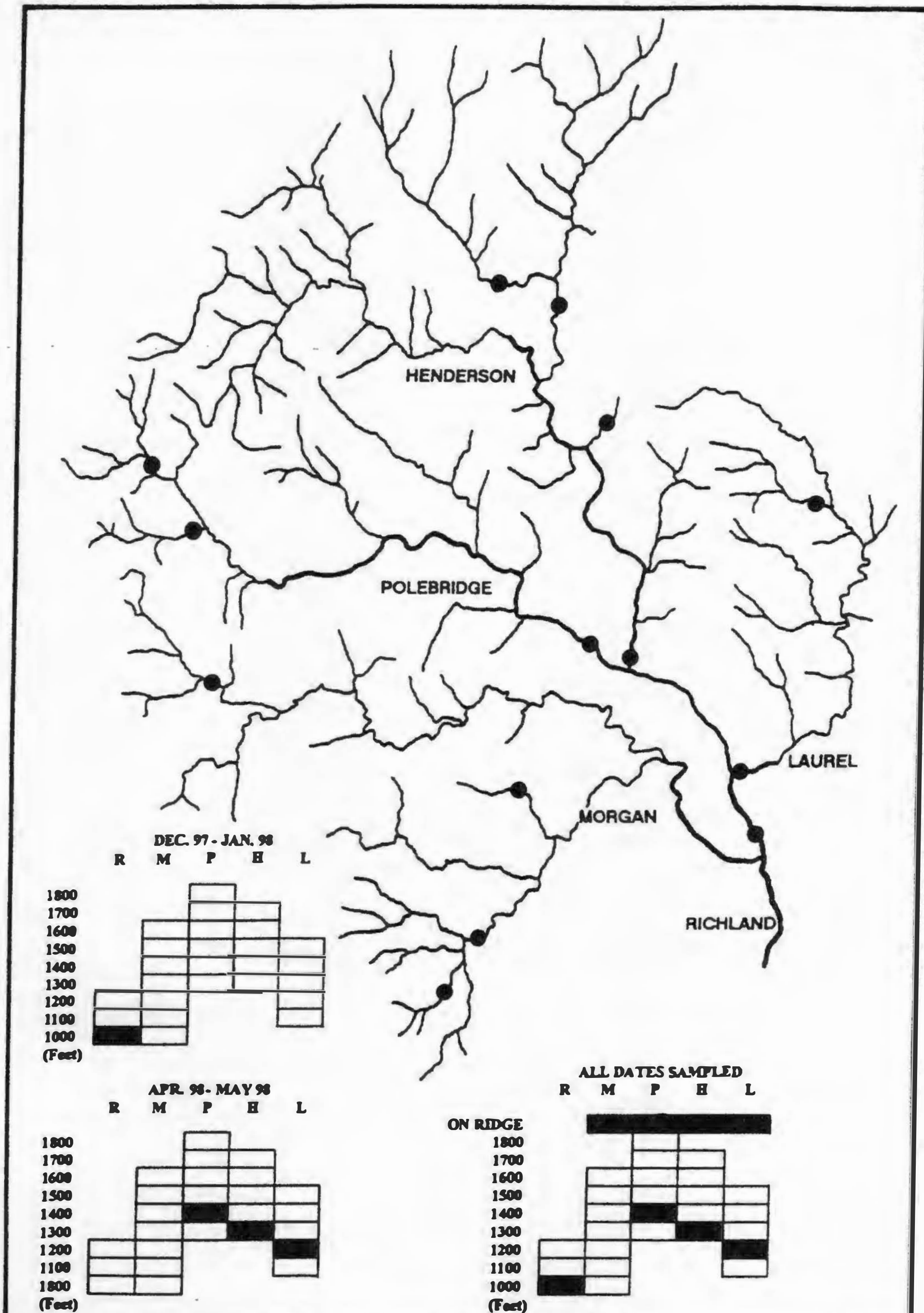

FIGURE 44. Distribution of *Diplectrona modesta* (Trichoptera, Family Hydropsychidae).

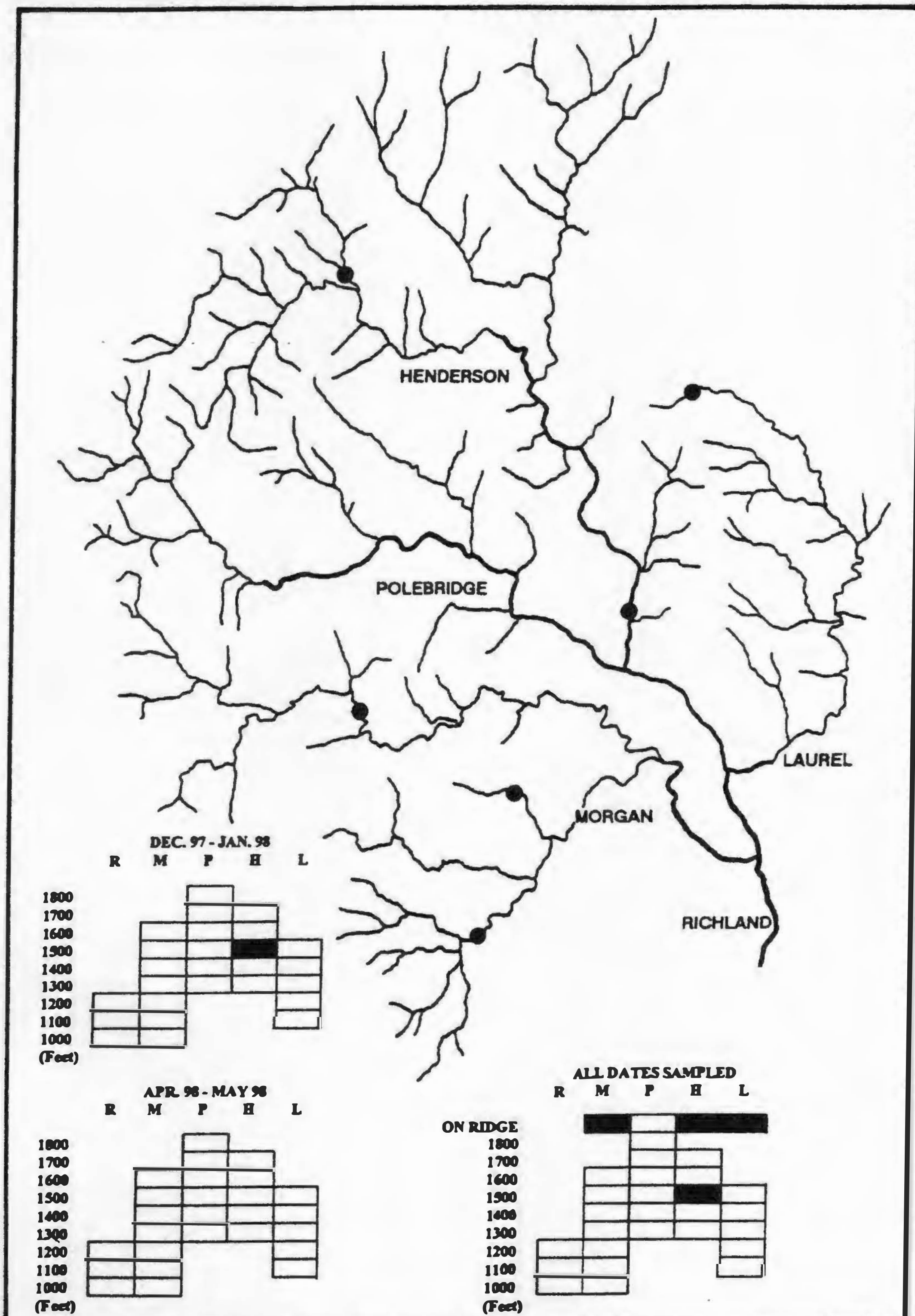

FIGURE 45. Distribution of *Cheumatopsyche sp.* (Trichoptera, Family Hydropsychidae).

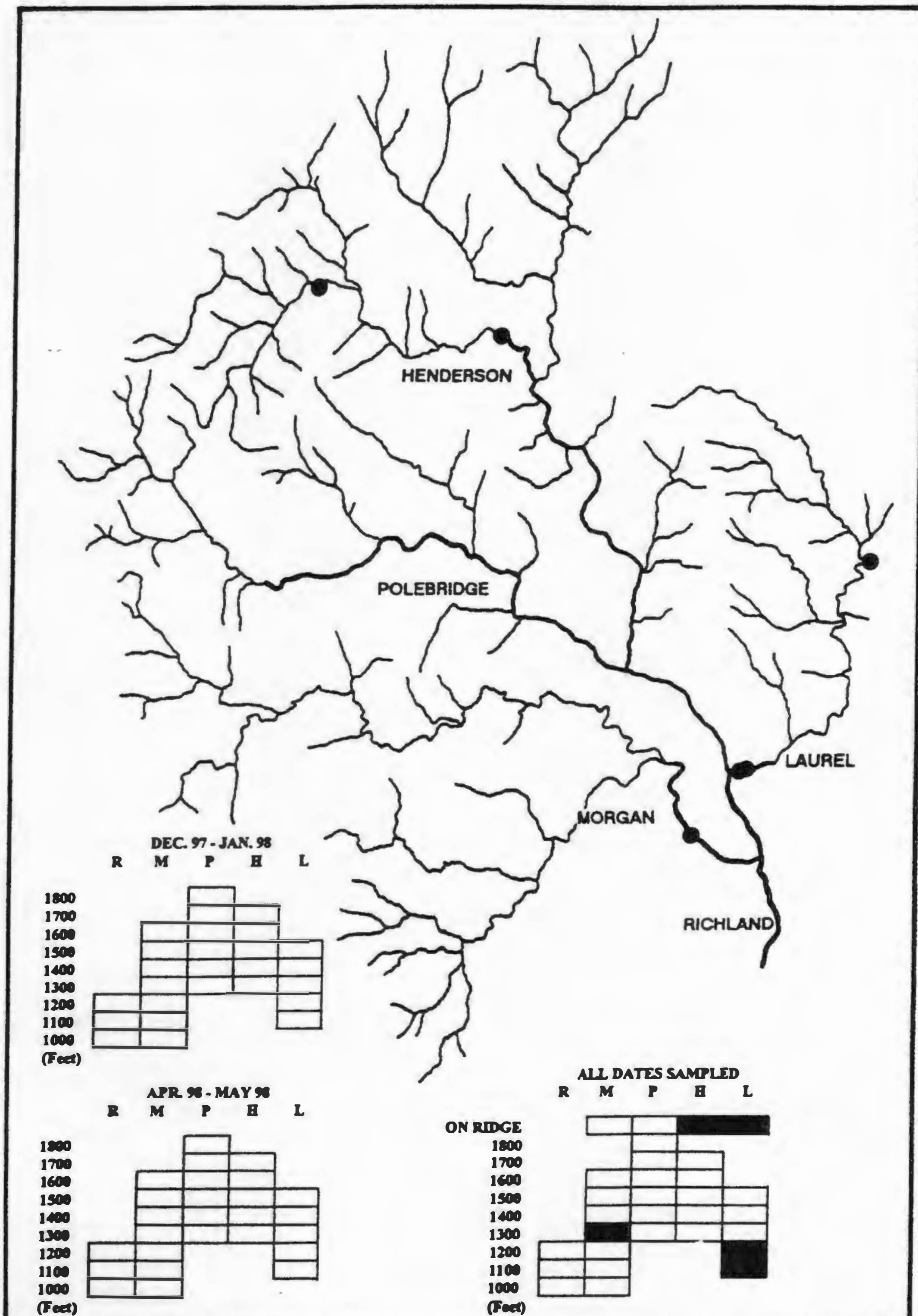

FIGURE 46. Distribution of *Hydropsyche betteni* (Trichoptera, Family Hydropsychidae)

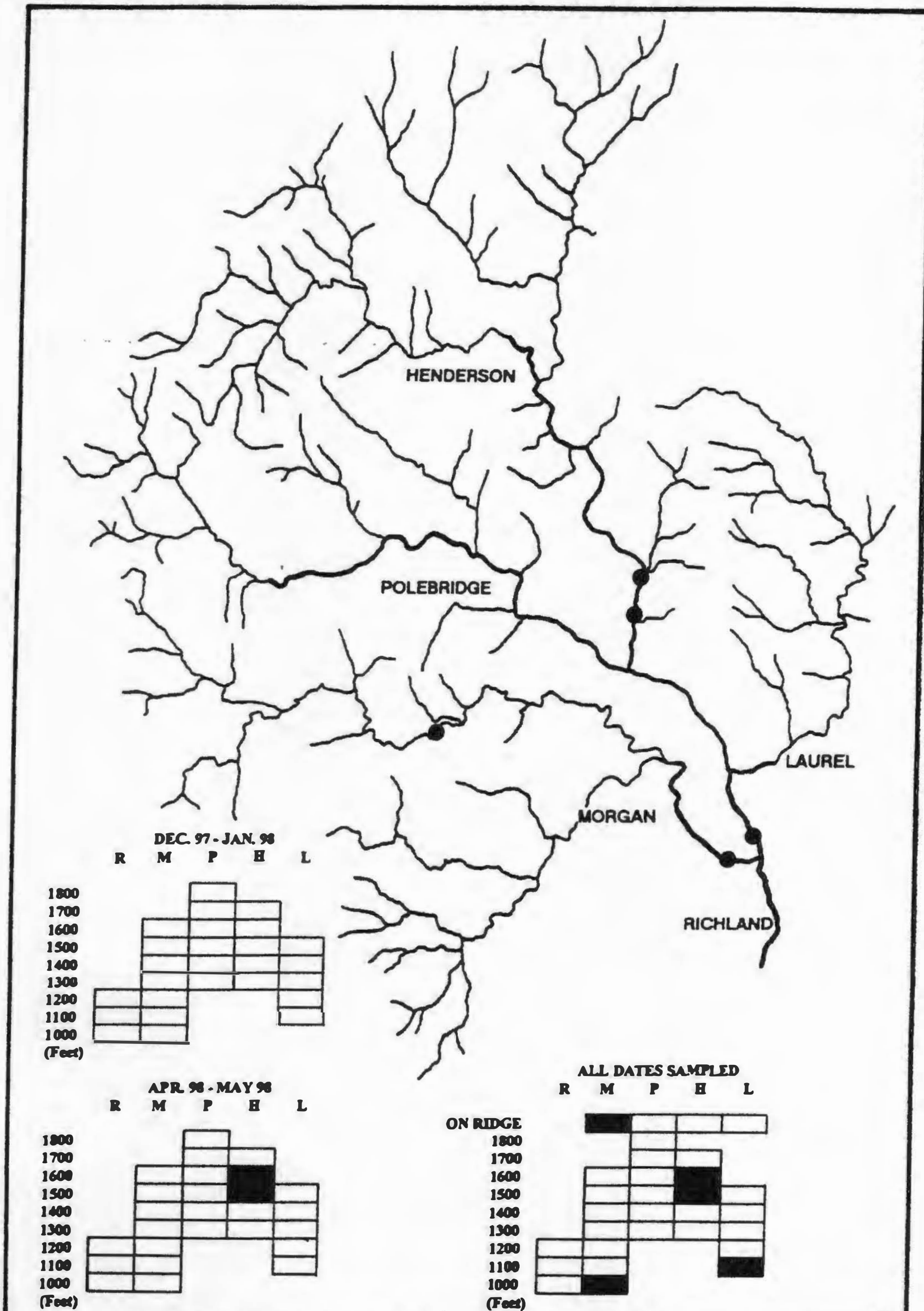

FIGURE 47. Distribution of *Ceratopsyche sparna* (Trichoptera, Family Hydropsychidae).

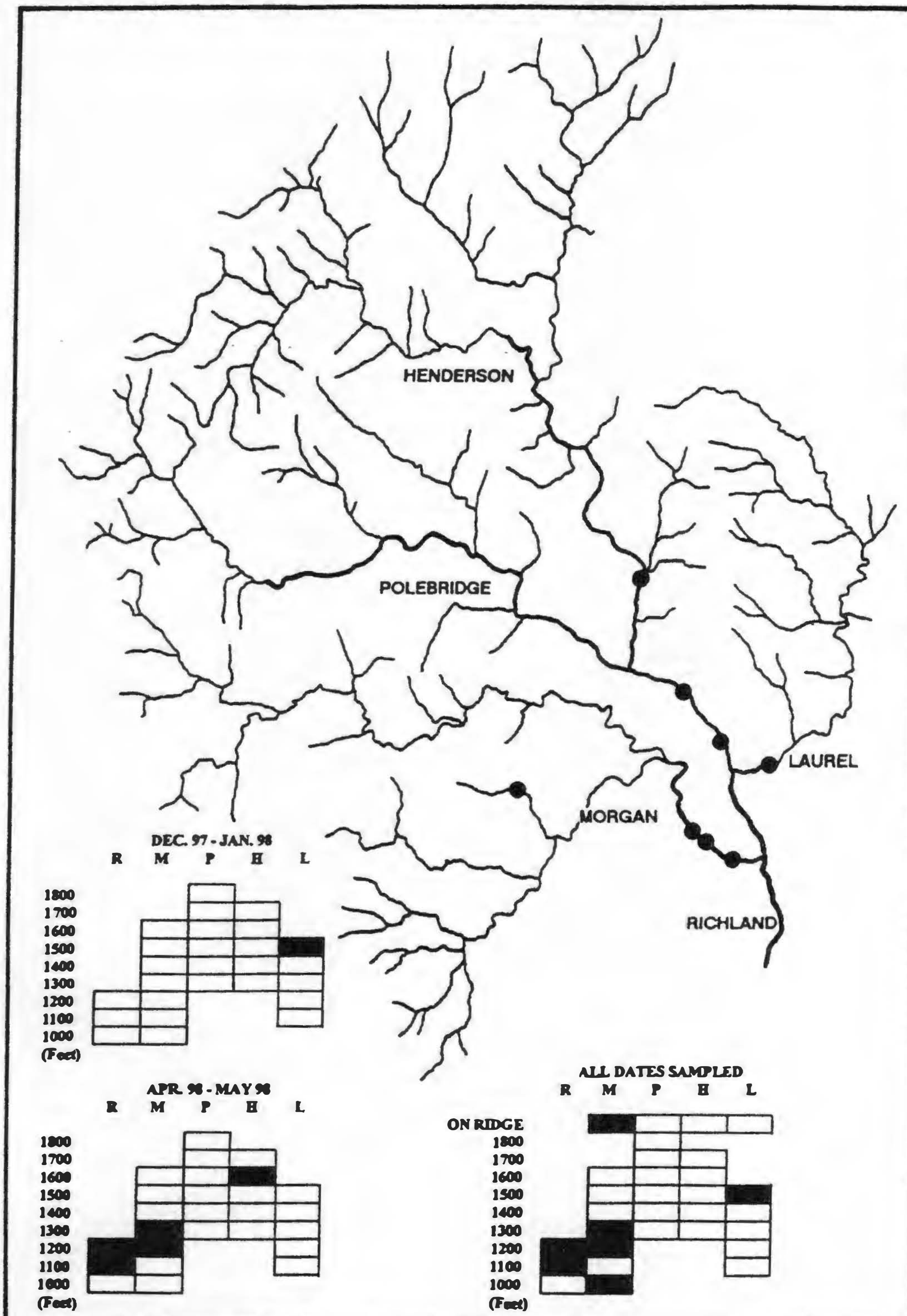

FIGURE 48. Distribution of *Dolophilodes* sp. (Trichoptera, Family Philopotamidae).

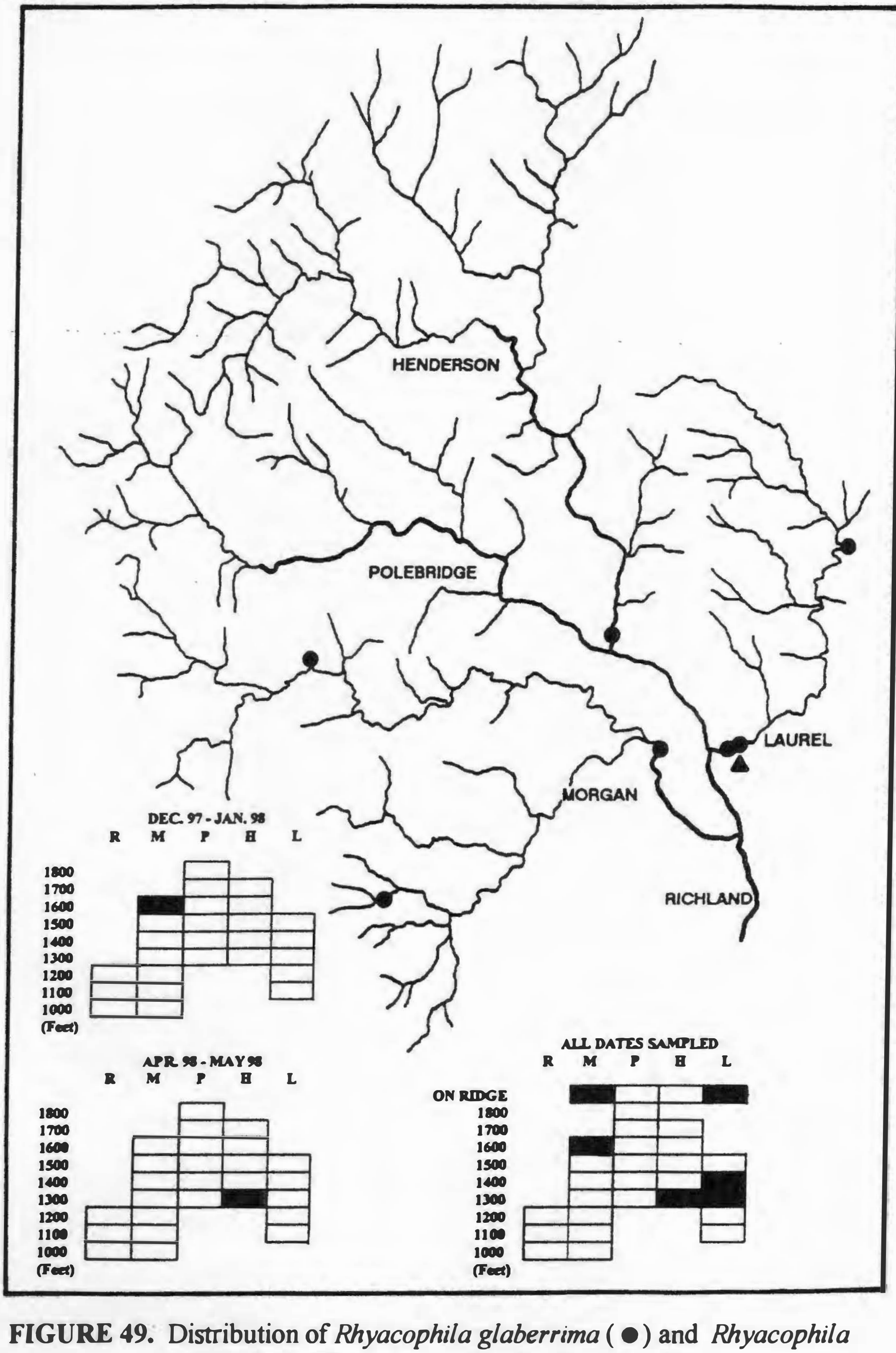

FIGURE 49. Distribution of *Rhyacophila glaberrima* (●) and *Rhyacophila torva* (▲) (Trichoptera, Family Rhyacophilidae).

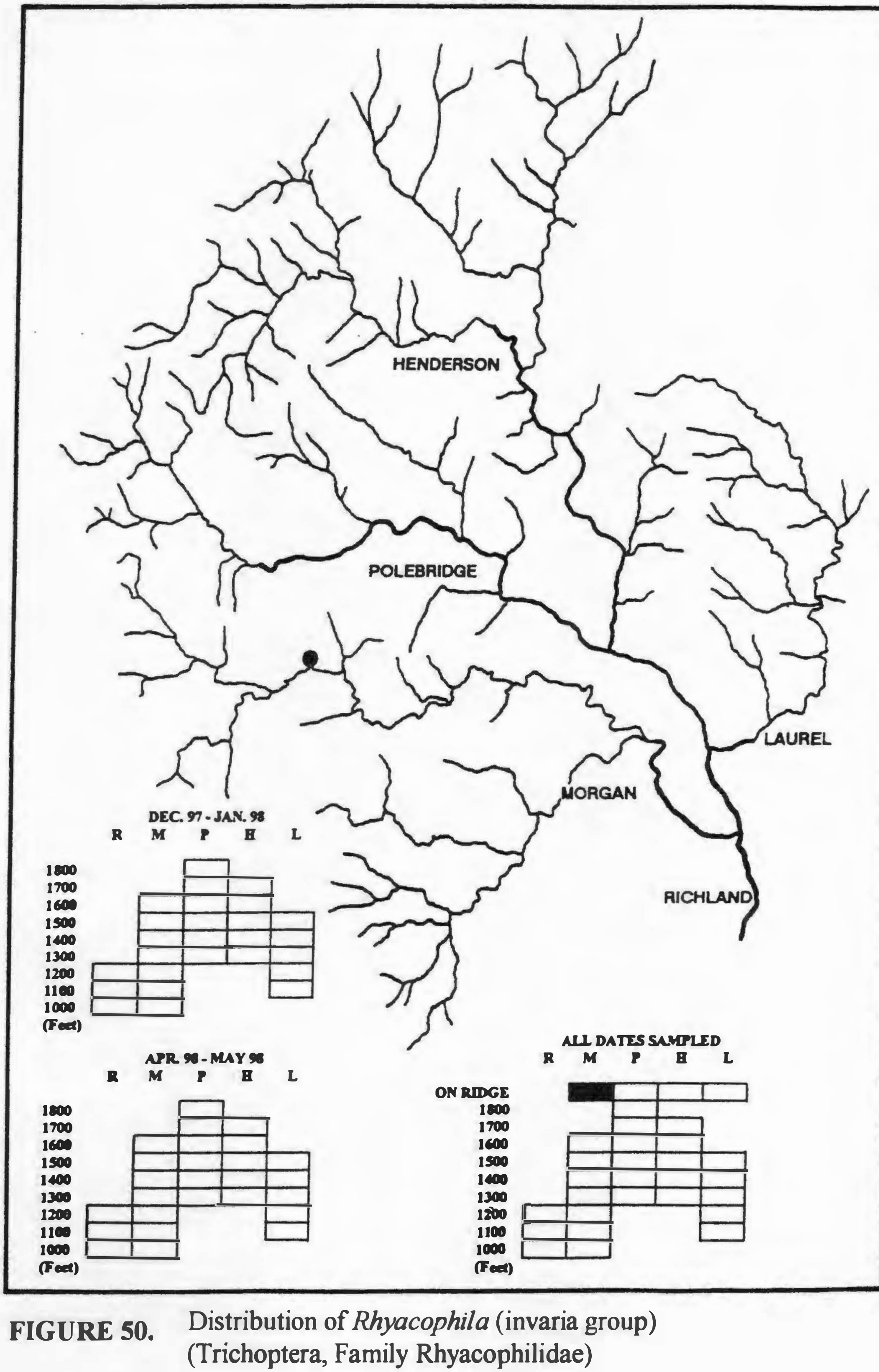

FIGURE 50. Distribution of *Rhyacophila* (invaria group) (Trichoptera, Family Rhyacophilidae)

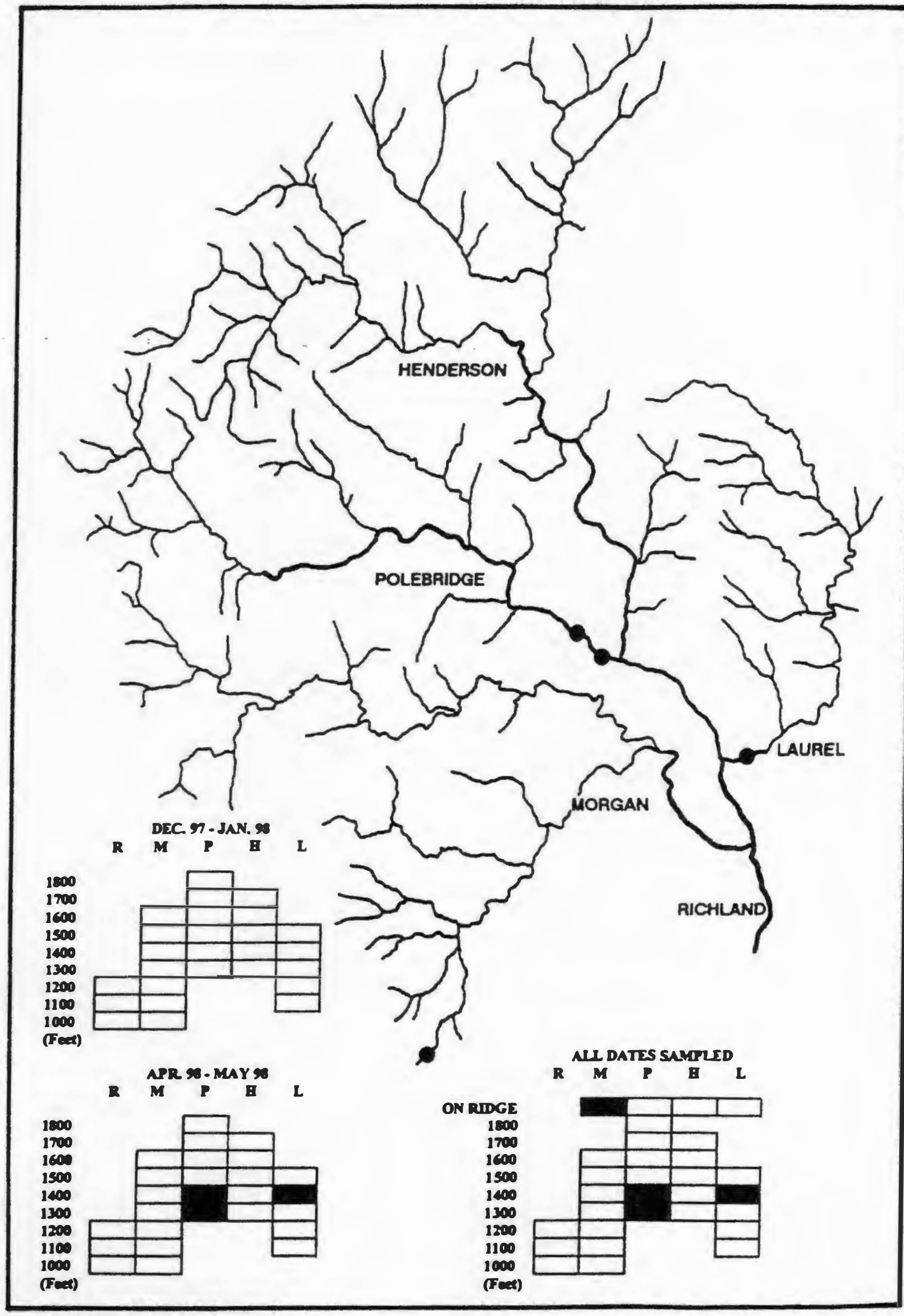

FIGURE 51. Distribution of *Lepidostoma* sp. (Trichoptera, Family Lepidostomatidae).

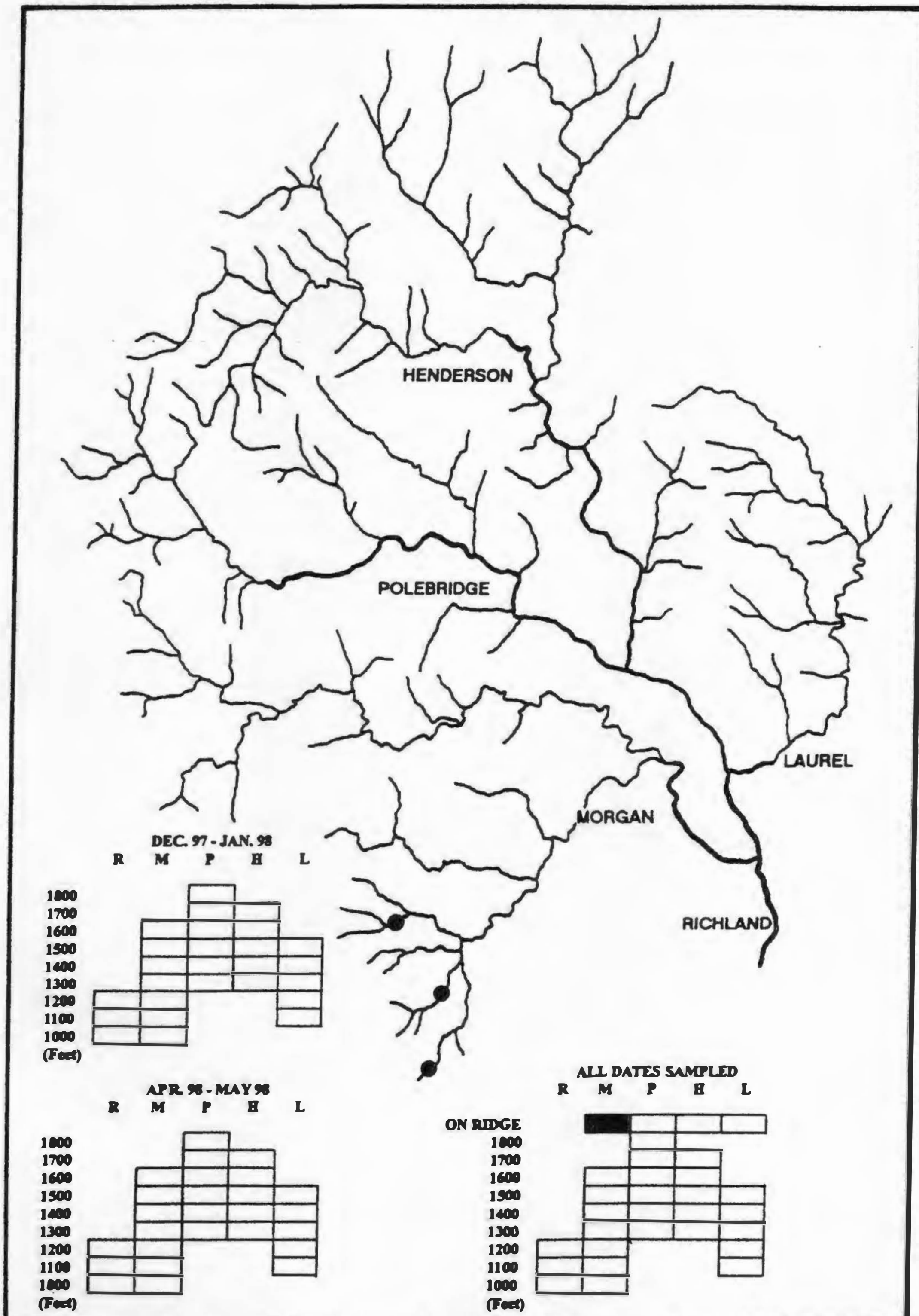

FIGURE 52. Distribution of *Ironoquia punctissima* (Trichoptera, Family Limnephilidae).

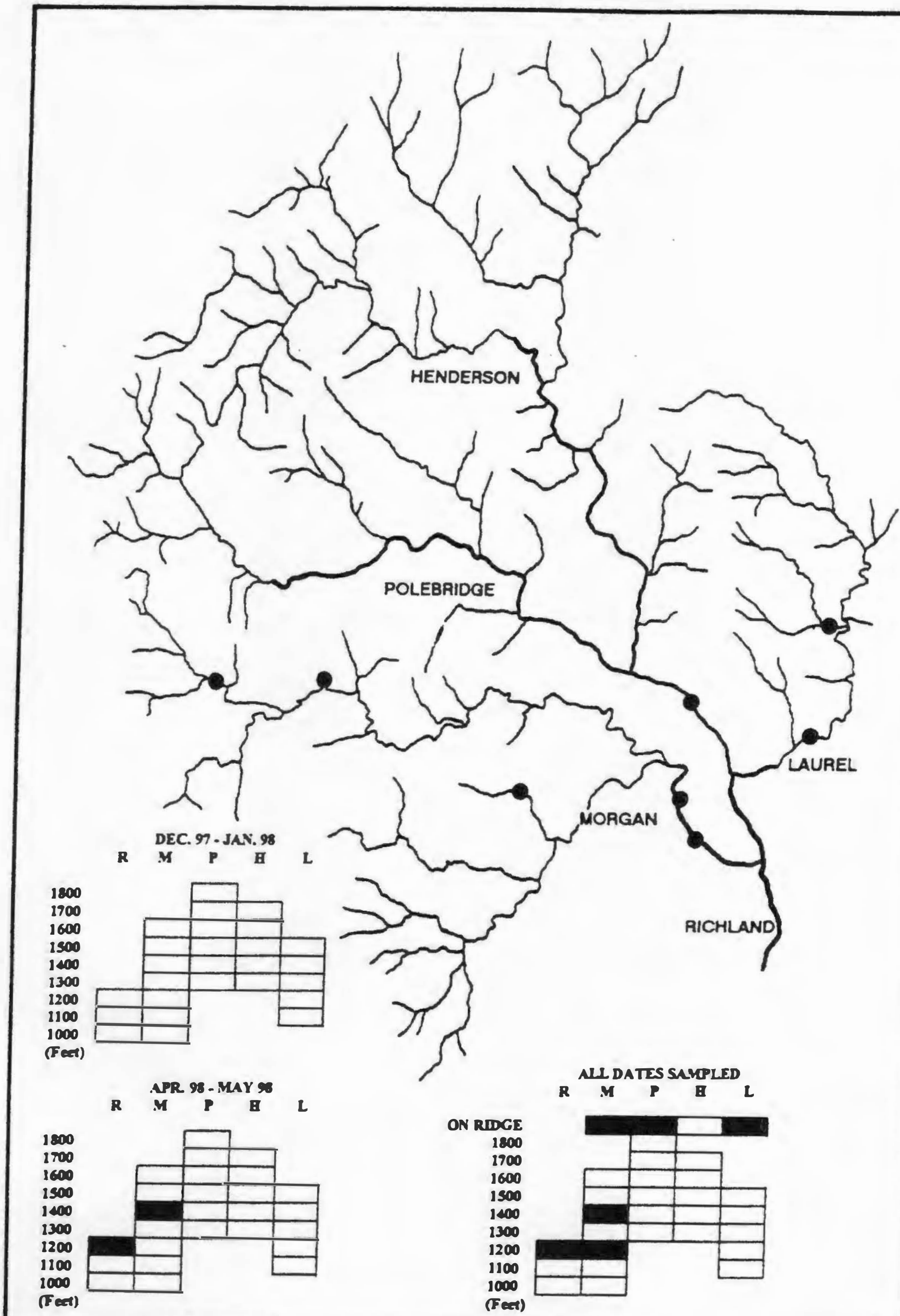

FIGURE 53: Distribution of *Pycnopsyche guttifer* (Trichoptera, Family Limnephilidae)

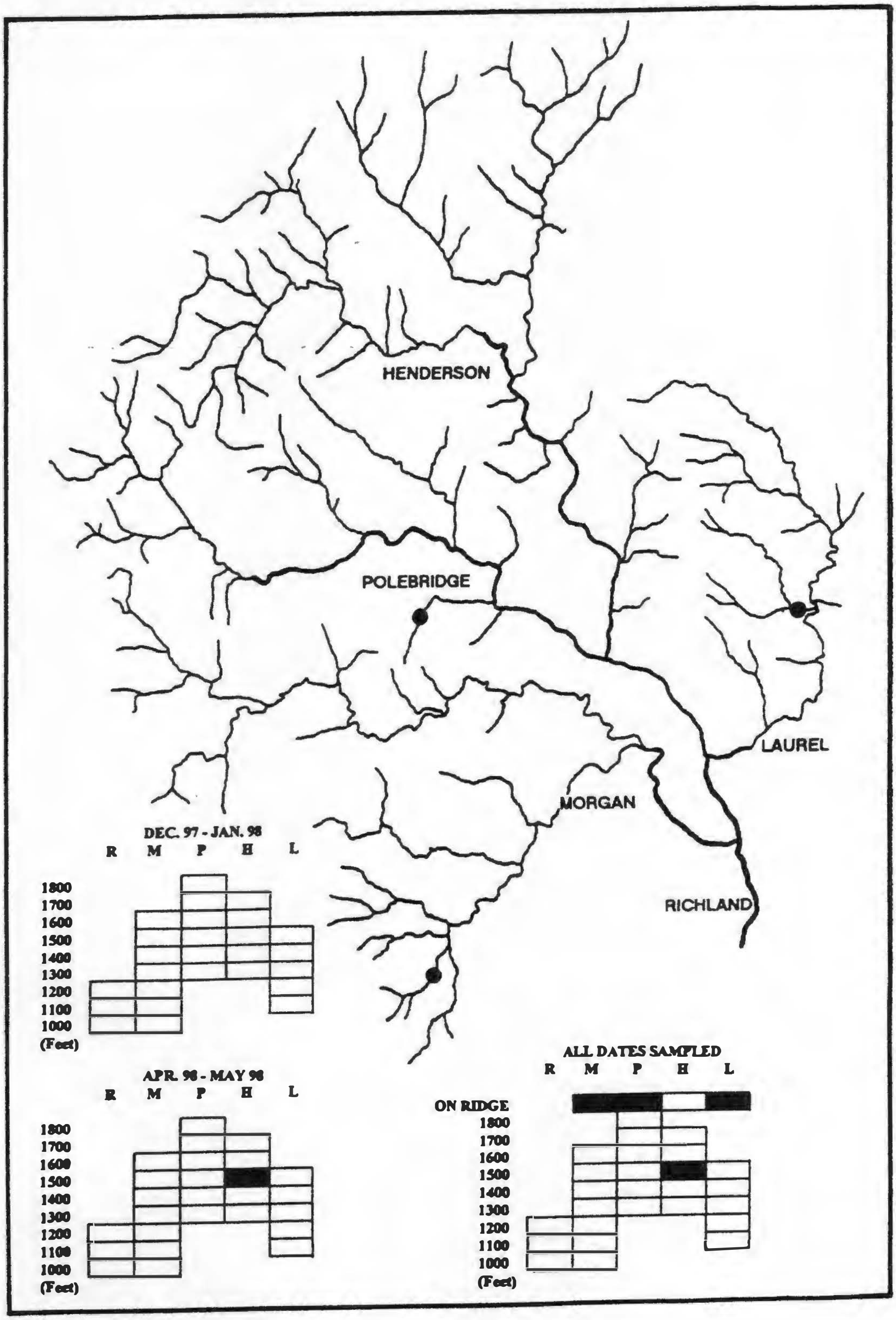

FIGURE 54. Distribution of *Playtocentropus radiatus* (Trichoptera, Family Limnephilidae)

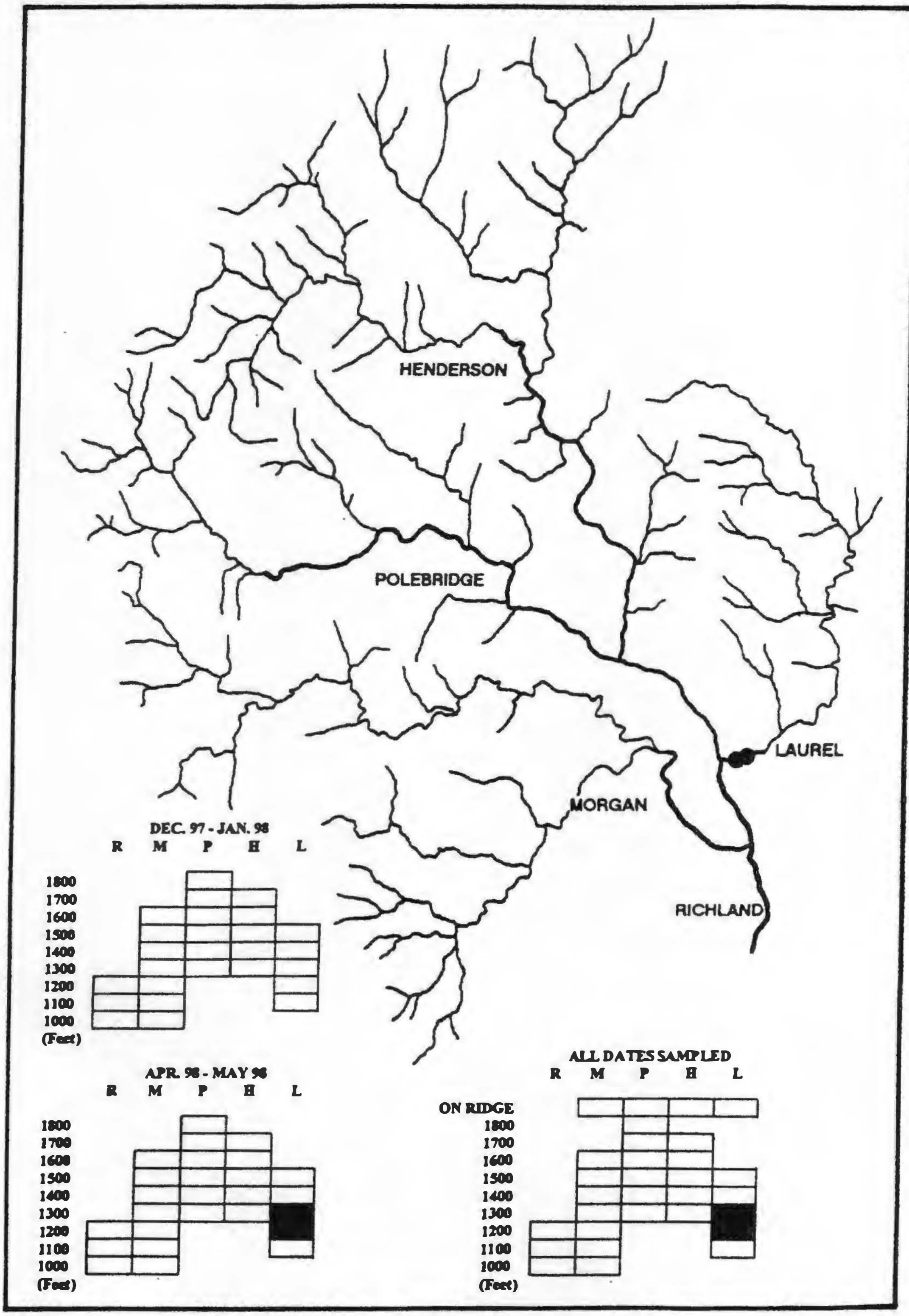

FIGURE 55. Distribution of *Neophylax aniqua* (Trichoptera, Family Uenoidae).

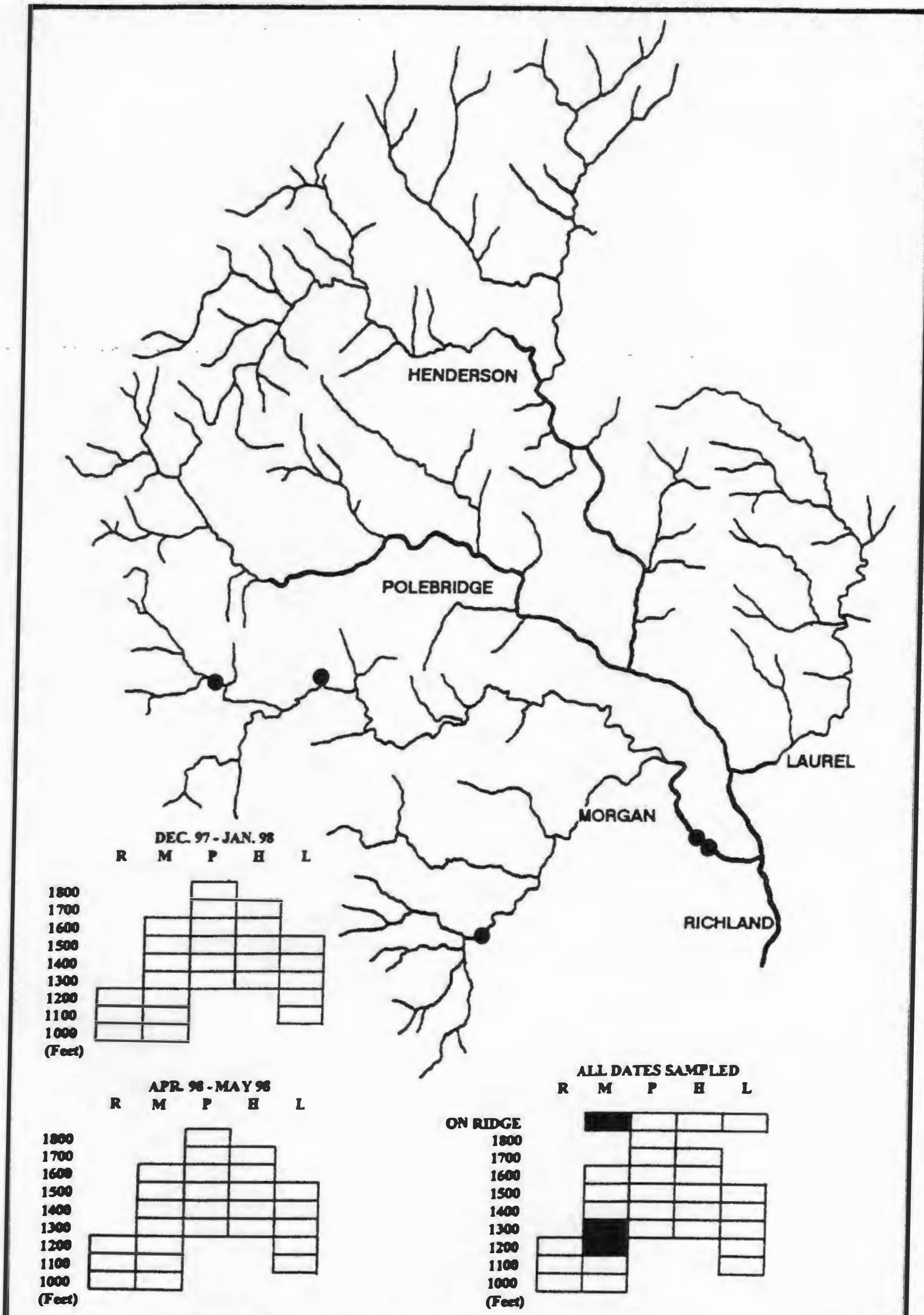

FIGURE 56. Distribution of *Neophylax wigginsi* (Plecoptera, Family Uenoidae)

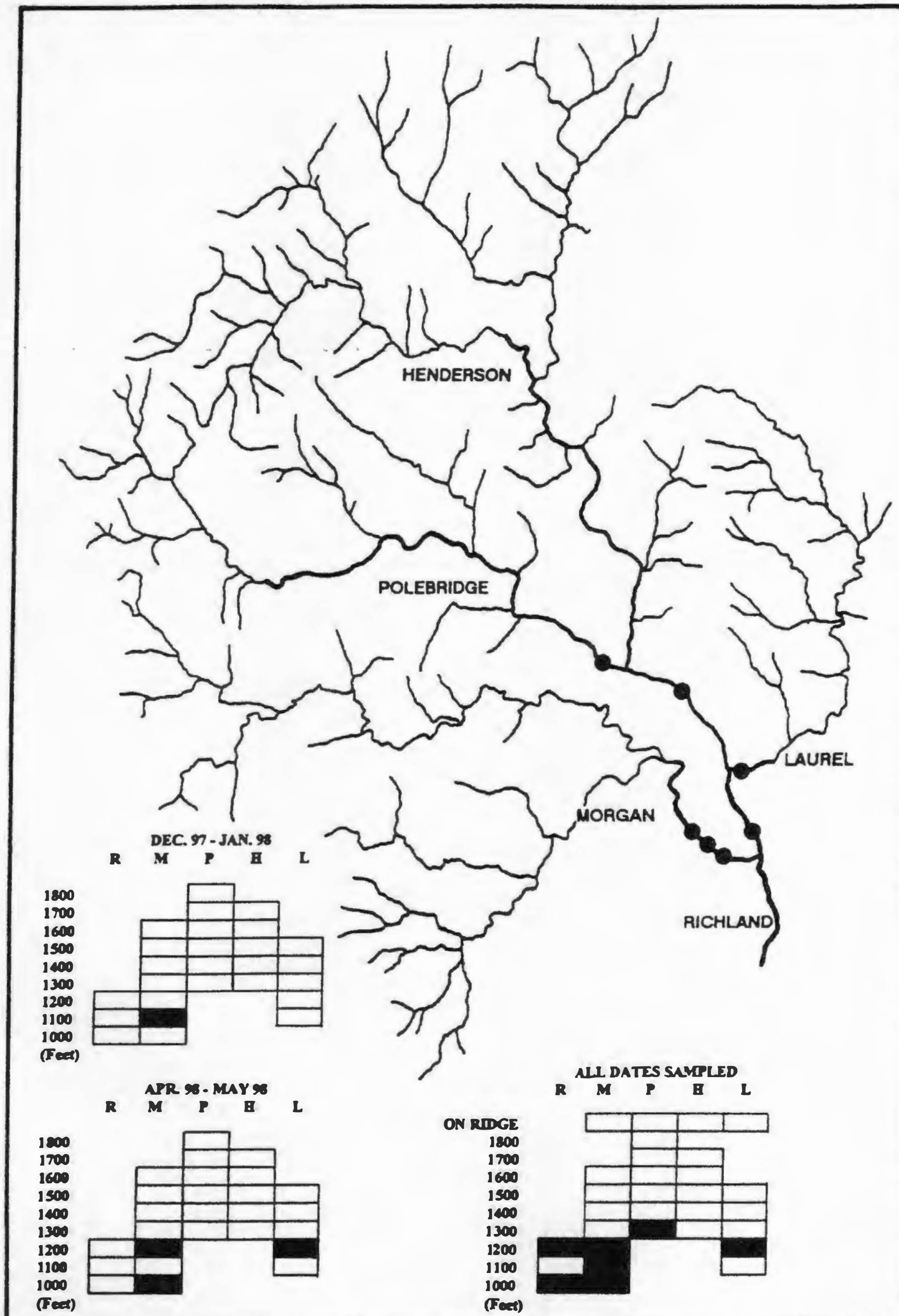

FIGURE 57. Distribution of *Psephenus herricki* (Coleoptera Family Psephenidae).

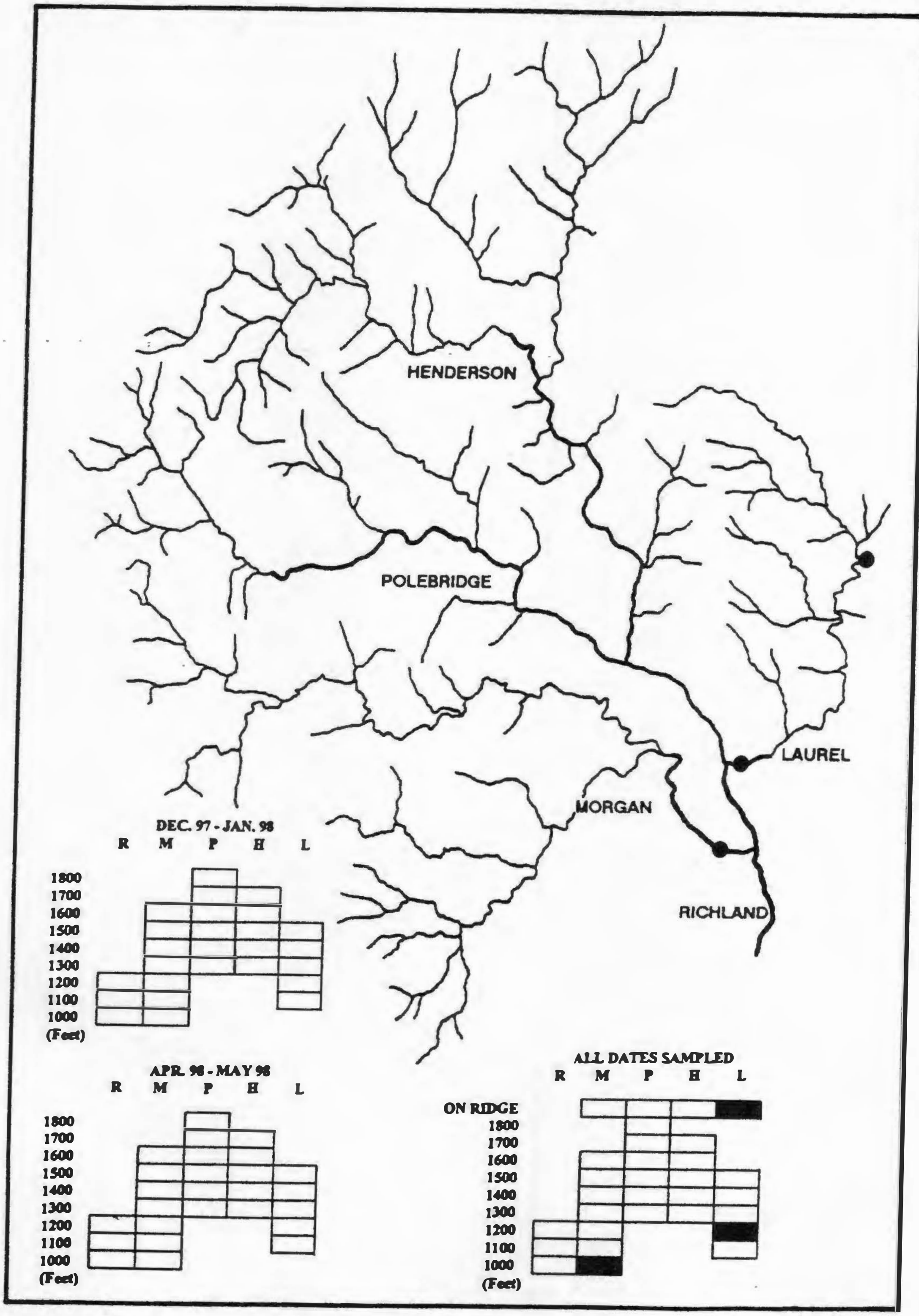

FIGURE 58. Distribution of *Ectopria* sp. (Coleoptera Family Eubriidae).

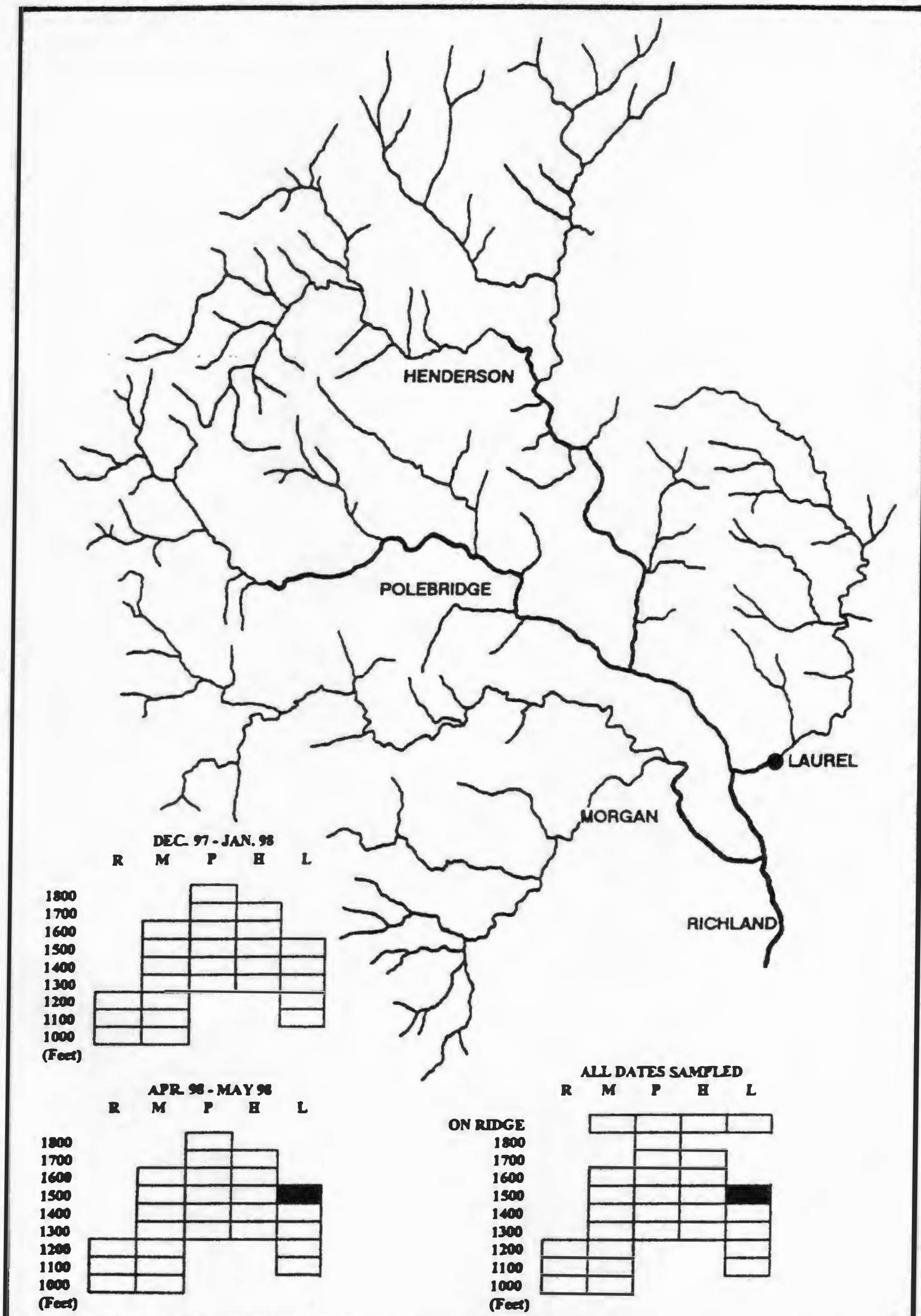

FIGURE 59. Distribution of *Antocha* sp. (Diptera, Family Tipulidae).

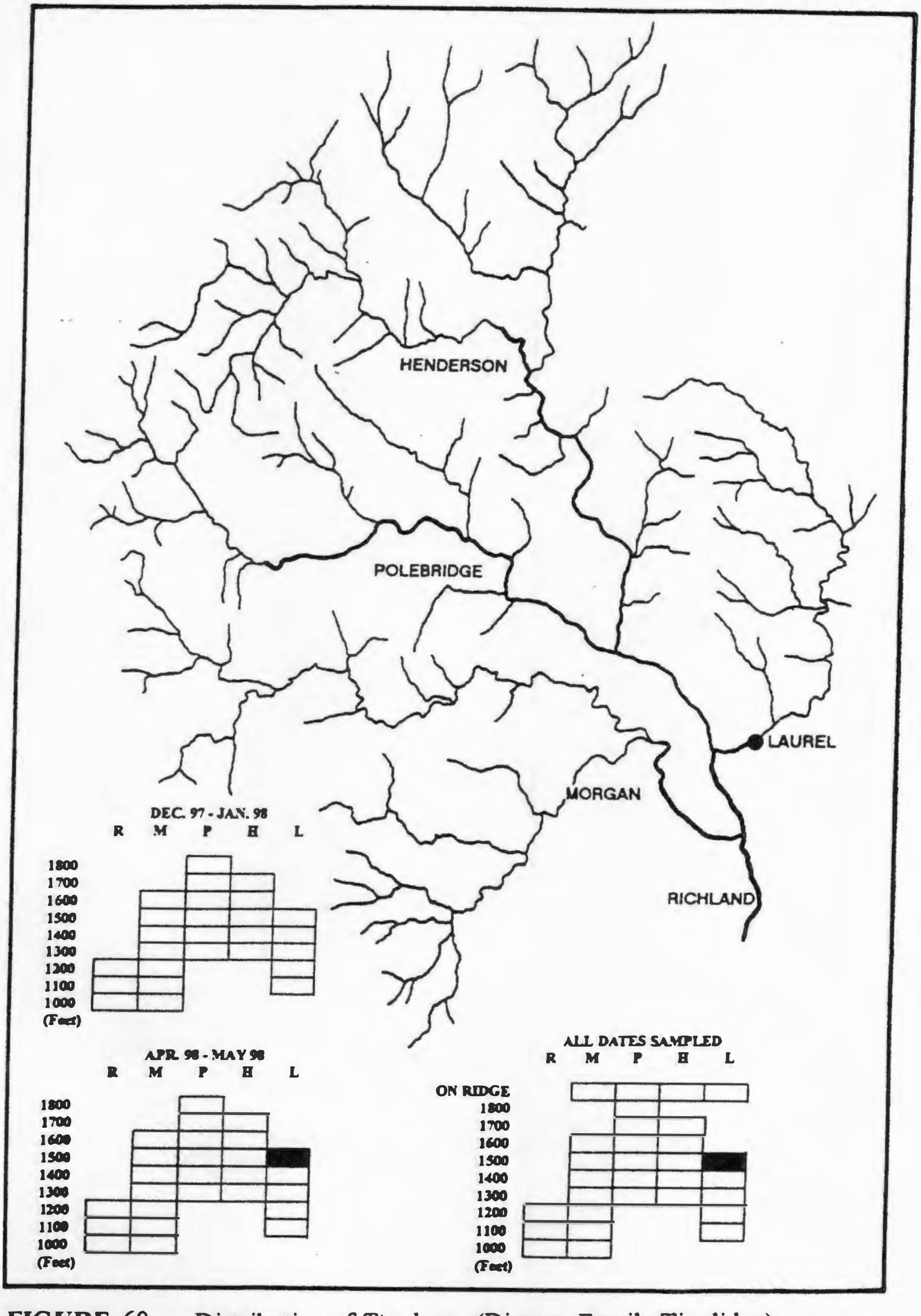

FIGURE 60. Distribution of *Tipula* sp. (Diptera, Family Tipulidae).

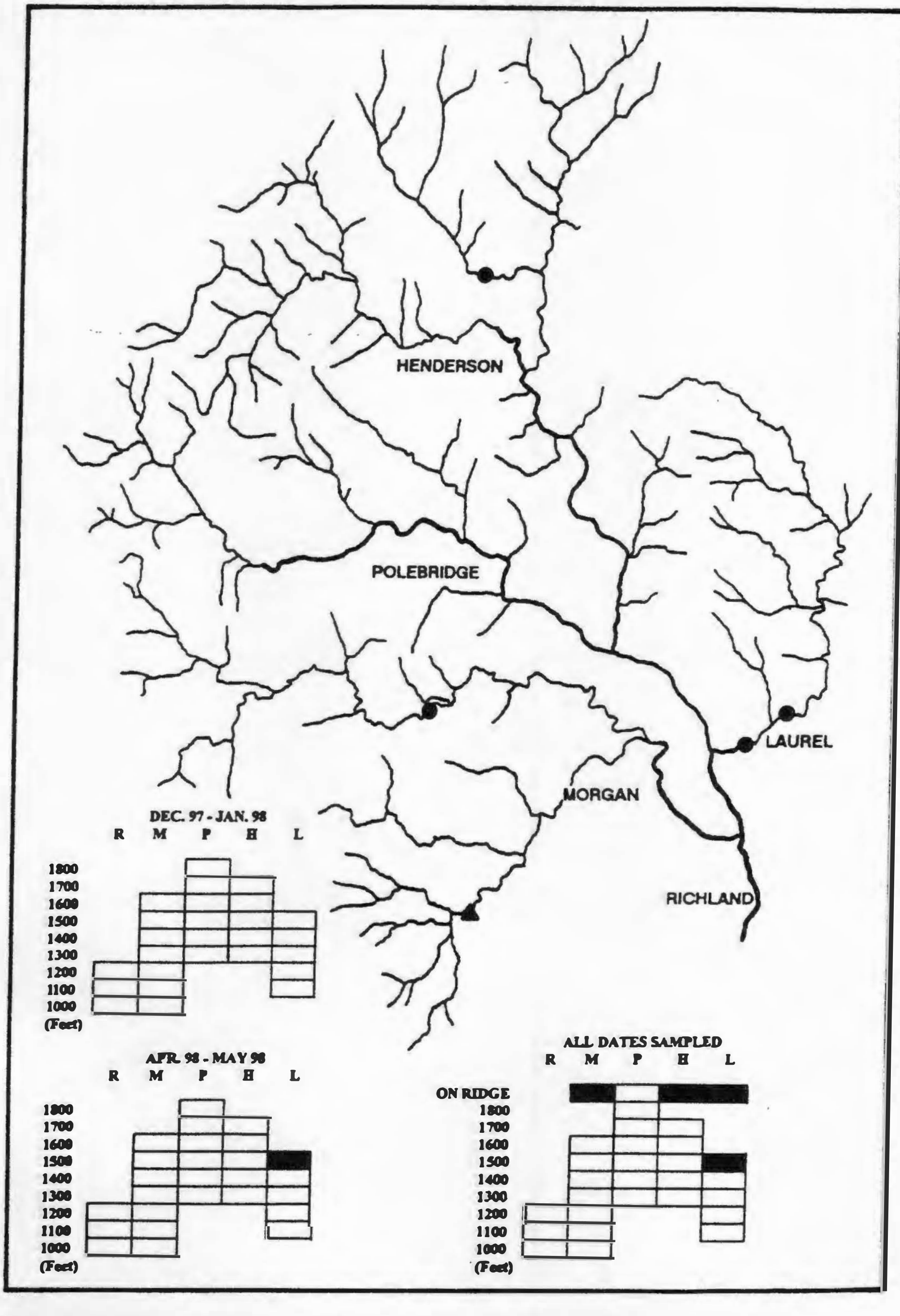

FIGURE 61. Distribution of Subfamily Orthocladinae (●) and Subfamily Chironominae/Tribe Chironomini (▲) (Diptera, Family Chironomidae).

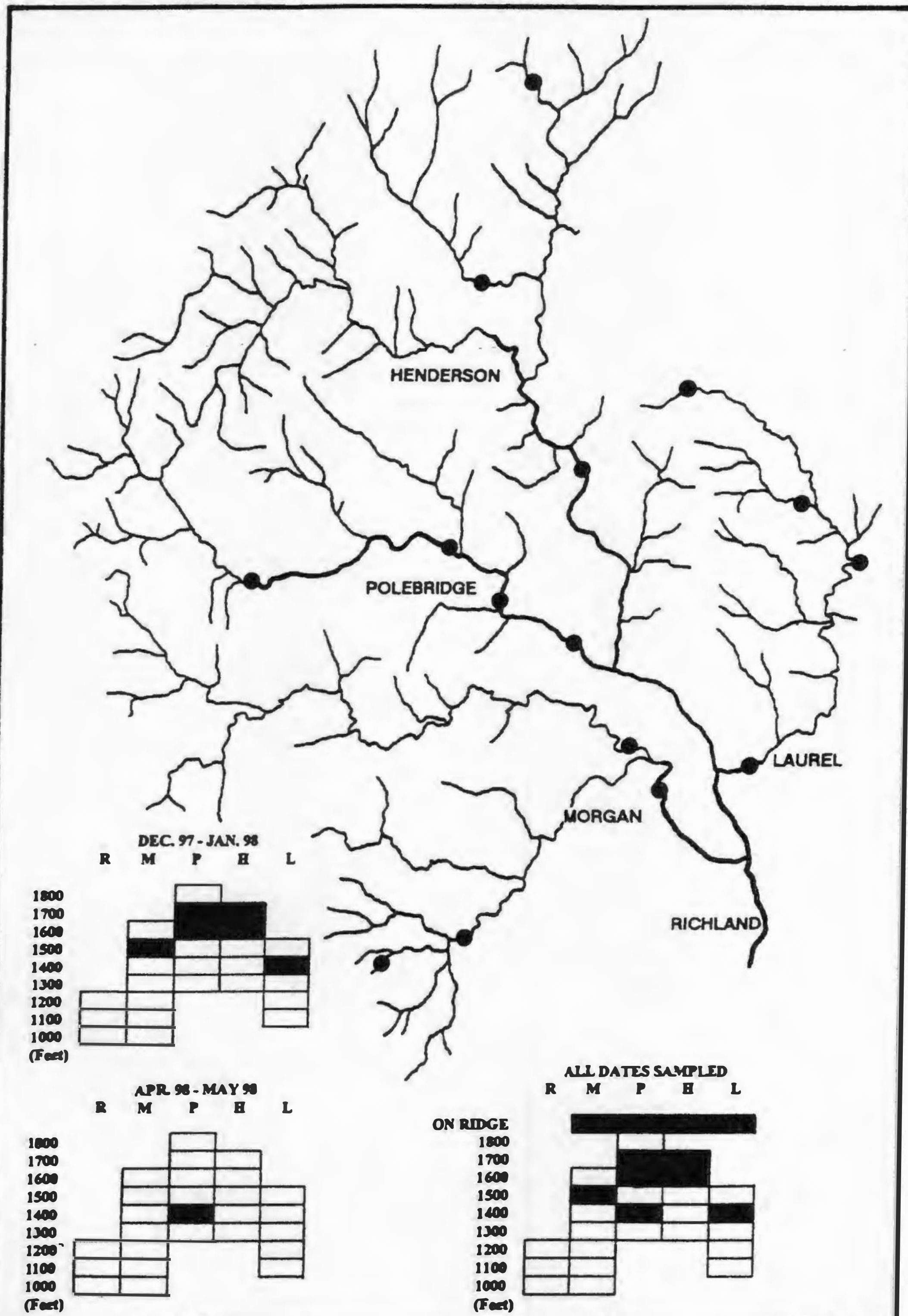

FIGURE 62. Distribution of *Prosimulium mixtum* (Diptera, Family Simuliidae).

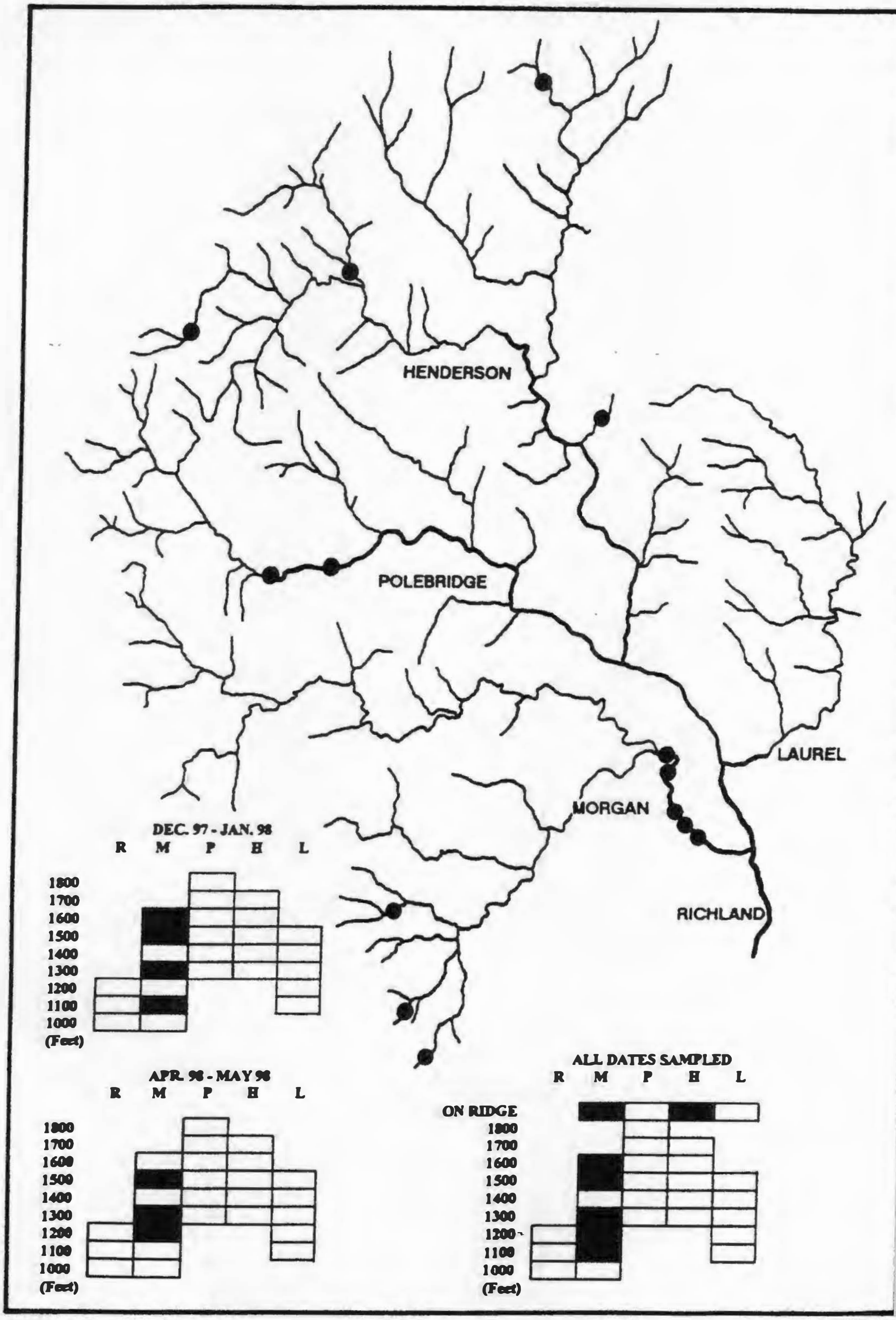

FIGURE 63. Distribution of *Gamarrus minus* (Amphipoda, Family Gammaridae).

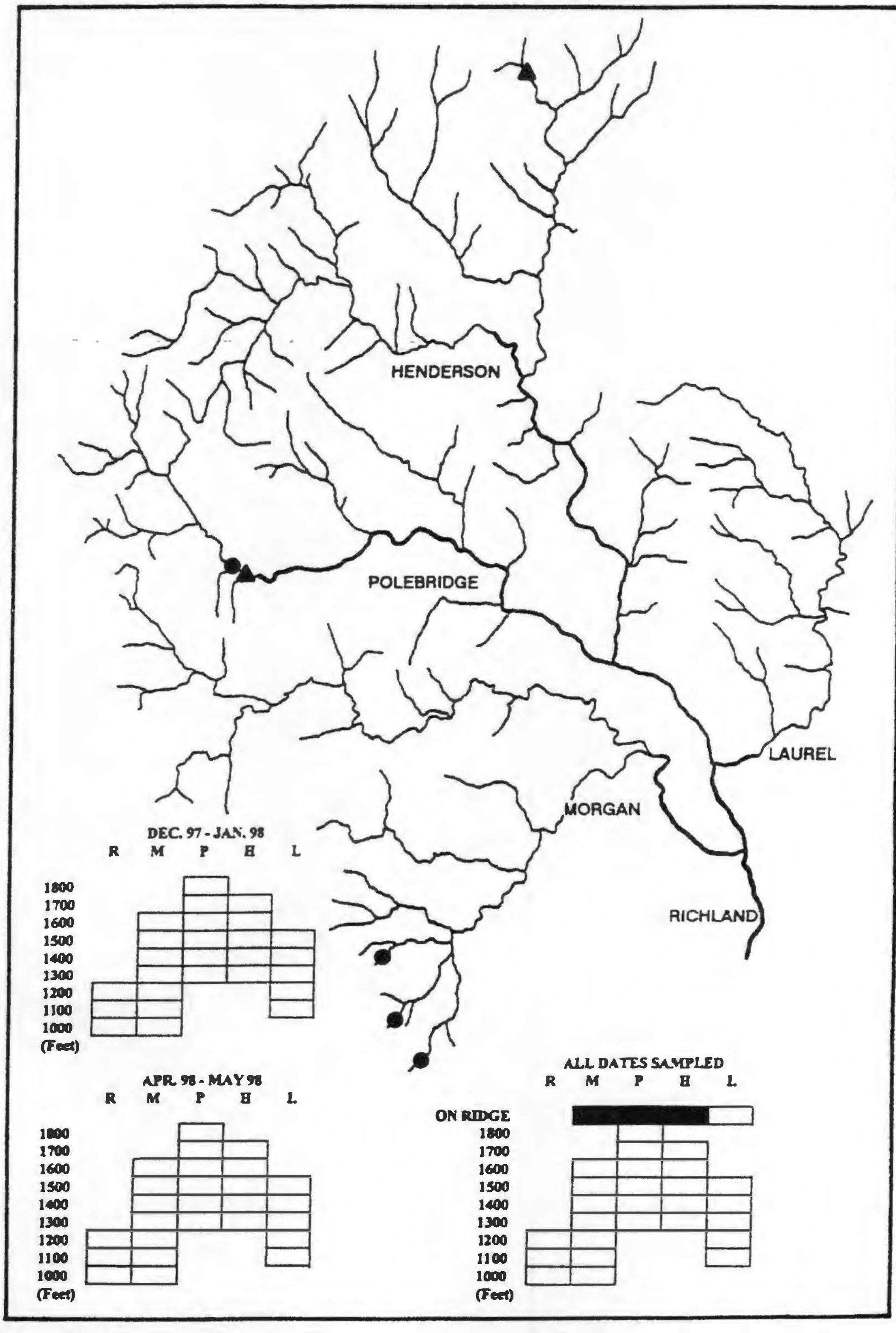

FIGURE 64. Distribution of *Asellus racovitzai* (●) and *Asellus forbesi* (▲) (Isopoda, Family Asellota).

VITA

Jack Pickett was born in Dayton, Tennessee on October 14, 1946. He attended schools in the public system of Kennesaw, Georgia, the Cobb County School System, where he graduated from North Cobb County High School in May, 1964. He attended Auburn University from June, 1964 to December, 1969. In June, 1970 he entered Washburn University (Kansas), where in June, 1973 he received the Bachelor of Science in Biology. In January, 1990 he entered the University of Tennessee at Chattanooga as a post-baccalaureate student in the Environmental Science Department. In August 1994, he entered the University of Tennessee at Knoxville where in May, 1999 he expects to receive the Master of Science in Ecology and Evolutionary Biology.

He is presently working as adjunct faculty at the Chattanooga State Technical Community College (Tennessee) in the Department of Biology and Environmental Science.